

Plant breeding

-Part 3

1. Quantitative inheritance
2. Inbreeding depression
3. Heterosis
4. Crop improvement
5. Breeding techniques
6. Role of mutation in crop improvement
7. Polyploidy in plant breeding
8. Distant hybridization in plant breeding
9. Role of biotechnology in crop improvement
10. Plant genetic resources

Quantitative inheritance

Qualitative characters

The characters produced by oligogenes

oligogenes- one or few genes with large and easily detectable effects which affects some characters

Quantitative characters

The characters are governed by polygenes

The development of many characters is very much affected by the genetic background and more particularly by the environment

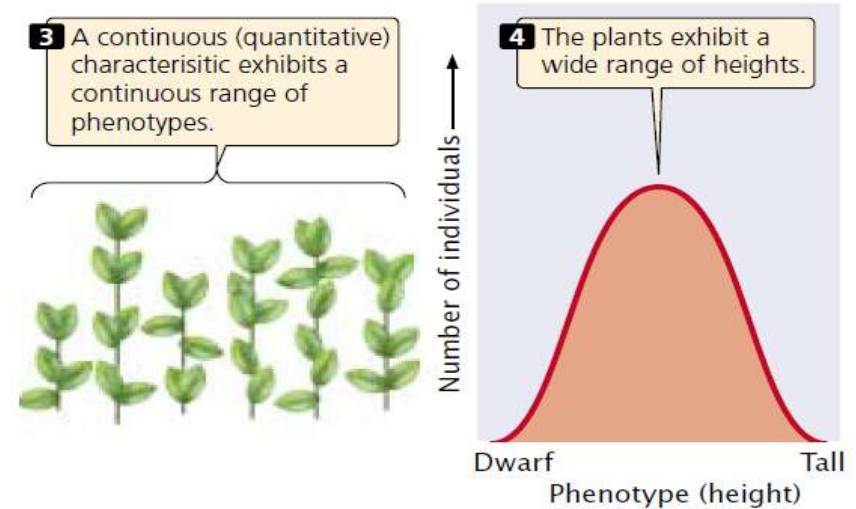
Inheritance of both follows the law of Mendel

But the effects of individual genes in the 2 cases are totally different

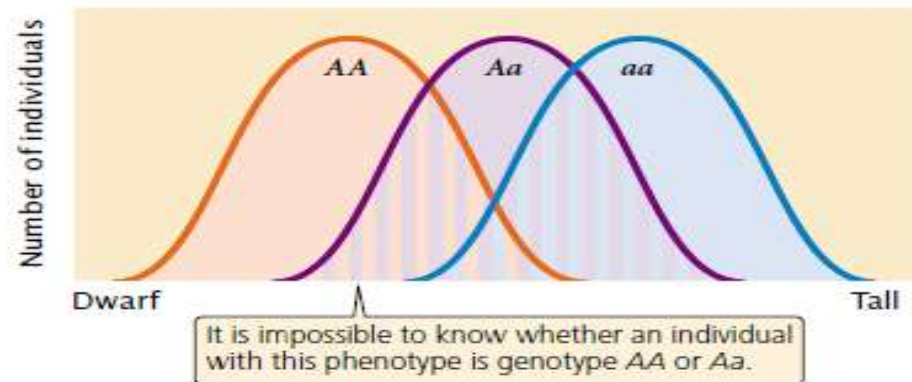
Quantitative characters

- Governed by several genes
- Each gene has small effect which is usually cumulative
- These characters are considerably affected by the environment
- Characters show a continuous variation and not possible to classify them into distinct classes
- Ex. Plant height, yield, days to flower, days to maturity, protein content, seed size
- Inheritance studies on quantitative characters have to employ statistical procedures
- A special branch of mathematics, Biometry, has developed as a result of the construction of special models and procedures to deal with the various aspects and problems of quantitative inheritance

(b) Continuous characteristic



Source: Benjamin A Pierce, Genetics, A conceptual approach, Page no. 639, 641



22.2 For a quantitative characteristic, each genotype may produce a range of possible phenotypes. In this hypothetical example, the phenotypes produced by genotypes AA, Aa, and aa overlap.

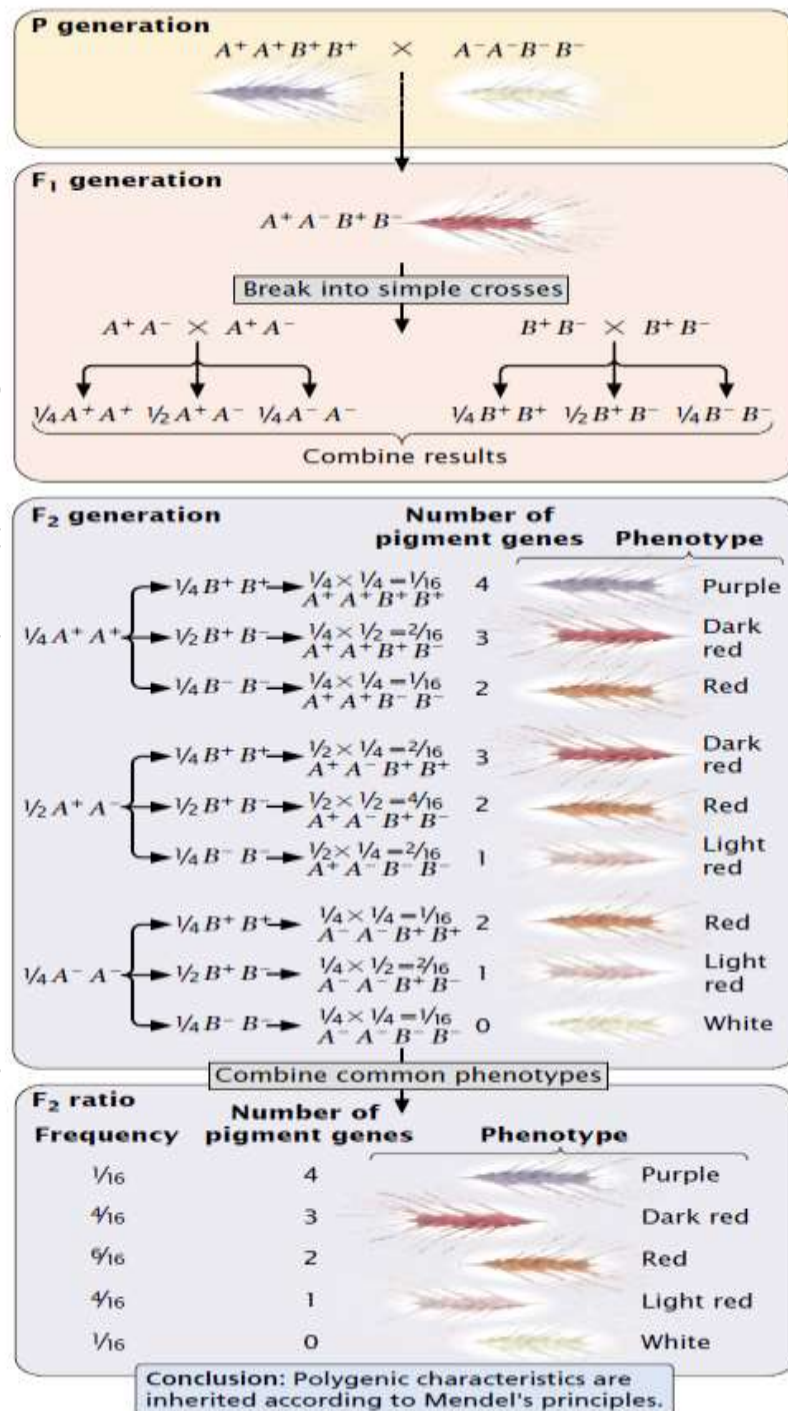
Kernel color in Wheat

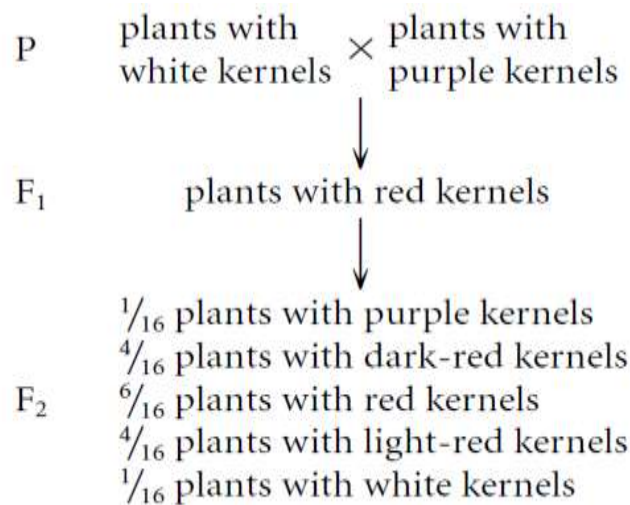
Aim: To illustrate how multiple genes acting on a characteristic can produce a continuous range of phenotypes

Nilsson-Ehle studied kernel color in wheat and found that the intensity of red pigmentation was determined by 3 unlinked loci, each of which had 2 alleles

Cross: Plants with white kernel and plants with purple kernels

Source: Benjamin A Pierce, Genetics, A conceptual approach, Page no. 643





(**FIGURE 22.4**). The probabilities of each of the phenotypes can then be obtained by adding the probabilities of all the genotypes that produce that phenotype. For example, the red phenotype is produced by three genotypes:

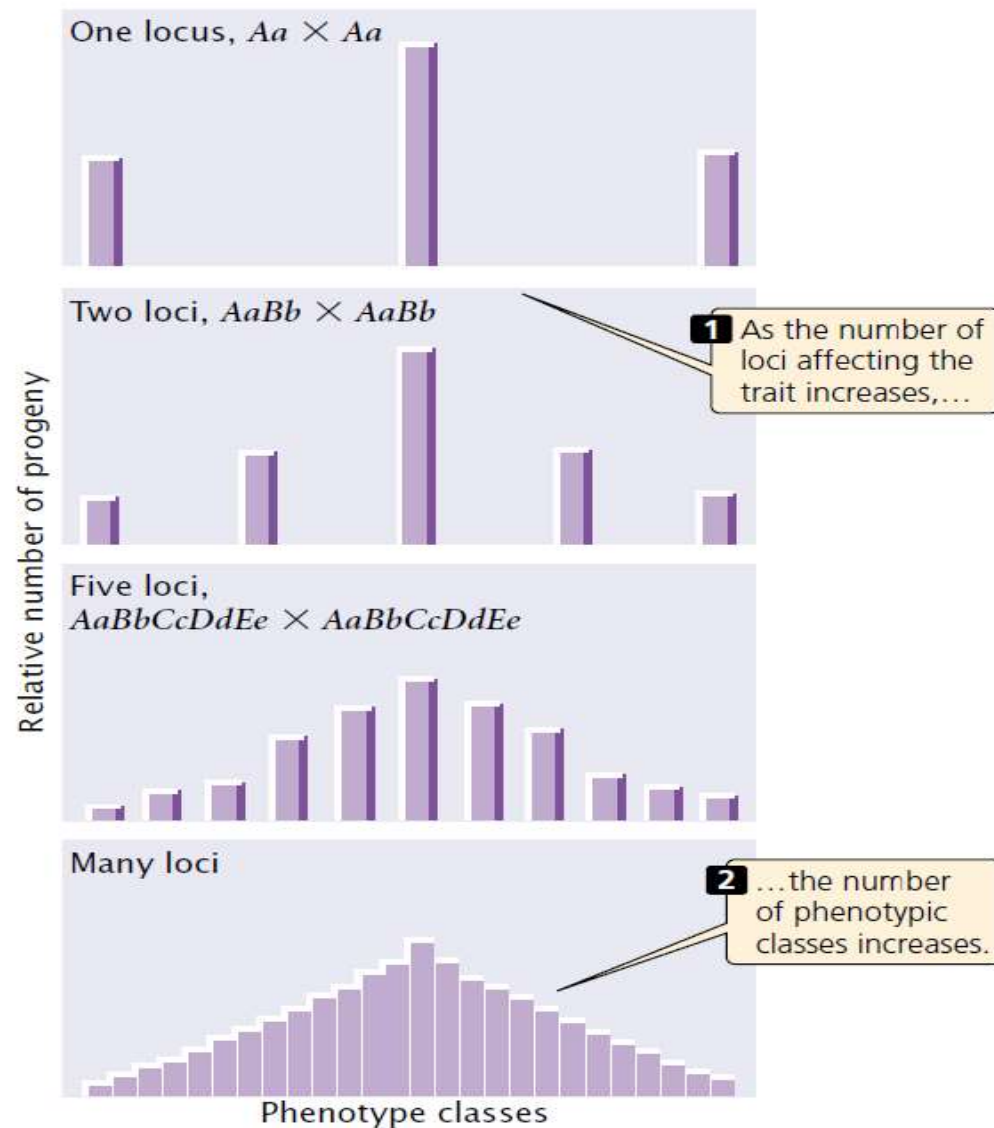
Genotype	Doses of pigment	Phenotype
$A^+A^+B^+B^+$	4	purple
$A^+A^+B^+B^-$	3	dark red
$A^+A^+B^-B^+$		
$A^+A^-B^+B^+$		
$A^+A^+B^-B^-$	2	red
$A^-A^-B^+B^+$		
$A^+A^-B^+B^-$		
$A^+A^-B^-B^-$	1	light red
$A^-A^-B^+B^-$		
$A^-A^-B^-B^-$	0	white

Genotype	Probability
$A^+A^+B^-B^-$	$\frac{1}{16}$
$A^-A^-B^+B^+$	$\frac{1}{16}$
$A^+A^-B^+B^-$	$\frac{1}{4}$

Thus, the overall probability of obtaining red kernels in the F₂ progeny is $\frac{1}{16} + \frac{1}{16} + \frac{1}{4} = \frac{6}{16}$. Figure 22.4 shows that the phenotypic ratio expected in the F₂ is $\frac{1}{16}$ purple, $\frac{4}{16}$ dark red, $\frac{6}{16}$ red, $\frac{4}{16}$ light red, and $\frac{1}{16}$ white. This phenotypic ratio is precisely what Nilsson-Ehle observed in his F₂ progeny, demonstrating that the inheritance of a continuously varying characteristic such as kernel color is indeed according to Mendel's basic principles.

Source: Benjamin A Pierce, Genetics, A conceptual approach, Page no. 642,643

Inference: certain characters are governed by genes that have small and cumulative effect. This in essence is the multiple factor hypothesis/ polygenic inheritance



22.5 The results of crossing individuals heterozygous for different numbers of loci affecting a characteristic.

Monogenic v/s polygenic inheritance

Monogenic inheritance	Polygenic inheritance
Single gene control	Multiple gene control
Simple Mendelian inheritance pattern	Complex inheritance pattern
Results in qualitative differences	Results in quantitative differences
Ex. Flower color, seed shape	Ex. Plant height, yield or disease resistance
Estimated using conventional methods and techniques	Estimated using statistical procedures and techniques

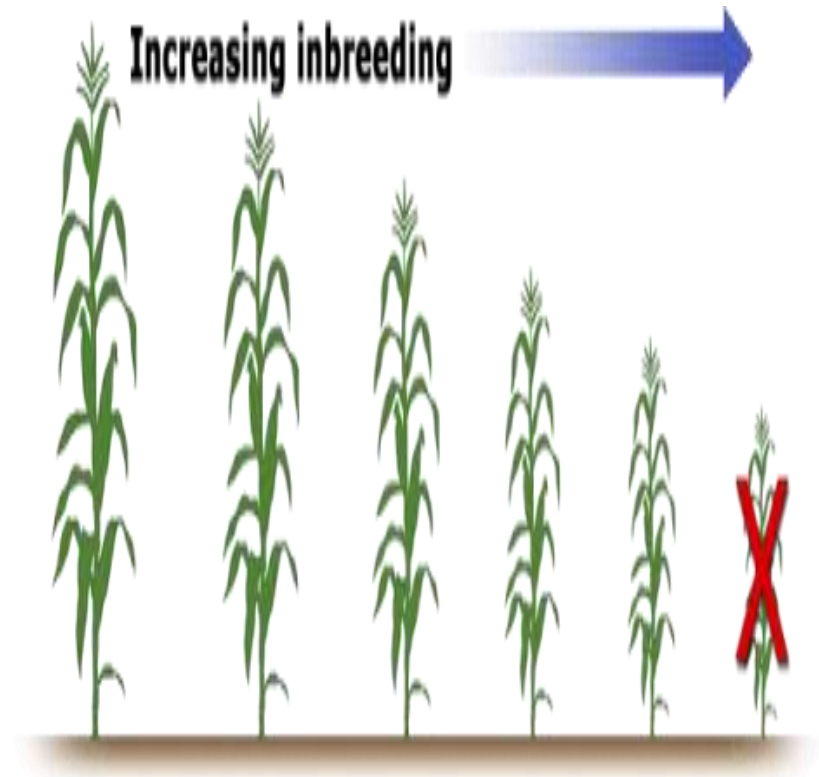
Inbreeding depression

Inbreeding depression

- **Inbreeding**- mating between individuals related by descent or ancestry
- When the individuals are closely related eg, in brother-sister mating or sib mating, the degree of inbreeding is high
- The highest degree of inbreeding is achieved by selfing
- **Chief effect of inbreeding:** Increase in homozygosity in progeny
- **Inbreeding depression**- the reduction or loss in vigour and fertility as a result of inbreeding

Effects of inbreeding:

- Reduction in vigour and reproductive capacity (fertility)
- Reduction in size of various plant parts and in yield
- Harmful recessive alleles appear after selfing
- Plants or lines carrying these alleles usually do not survive
- Appearance of lethal and sublethal alleles
- Separation of the population into distinct lines
- Increase in homozygosity



<https://iastate.pressbooks.pub/cropgenetics/chapter/inbreeding-and-heterosis-2/>

Degree of inbreeding depression:

1. High inbreeding depression:

- Ex. Alfalfa, Carrot, hayfield tarweed
- Loss in vigour and fertility is so great that very few lines can be maintained after 3 or 4 generations of inbreeding
- Lines that do survive show greatly reduced yields
- Less than 25% of yield of open pollinated varieties

2. Moderate inbreeding depression:

- Ex. Maize, Jowar, Bajra
- Many lethal and sublethal types appear in the selfed progeny, but a substantial proportion of the population can be maintained under self pollination
- Appreciable reduction in fertility and many lines reproduce so poorly that they are lost
- However large number of inbred lines can be obtained which yield upto 50% of open pollinated varieties
- Production and maintenance of inbred lines are relatively easier in these species than in high degree of inbreeding depression

3. Low inbreeding depression:

- Ex. Onion, Cucurbits, Rye, Sunflower, Hemp, Timothy grass
- Only small proportion of the plants show lethal or sublethal characteristics
- Loss in vigour and fertility is small
- Rarely a line cannot be maintained due to poor fertility
- Reduction in yield is due to inbreeding is small or absent
- Some of the inbred lines may yield as much as the open pollinated varieties from which they were developed

4. No inbreeding depression:

- Ex. Self pollinated species
- Do show Heterosis
- It is because these species reproduce by self fertilization and as a result have developed homozygous balance
- In cross pollinated species exhibit heterozygous balance

Heterosis

Heterosis

- Used by Shull in 1914
- Defined as the superiority of an F1 Hybrid over both its parents in terms of yield or some other characters
- Manifested as an increase in vigour, size, growth rate, yield or some other characters
- Often superiority of F1 is estimated over the average of the two parents, or the mid parent
- If the hybrid is superior to the mid parent, it is regarded as Heterosis (Average Heterosis)
- Heterosis estimated over the superior parent- Heterobeltiosis
- Heterosis estimated in relation to the best commercial variety- Economic/ useful Heterosis
- In 1944, Powers suggested that the term Heterosis should be used only when the hybrid is either superior or inferior to both the parents
- Other situations should be regarded as partial or complete dominance

Cross I

Inbreed A X Inbreed B
AAbbCCdd AA bbCCdd

F₁ hybrid
AAbbCCdd

No heterosis

Cross II

Inbreed A X Inbreed B
AAbbCCdd aaBBccDD

F₁ hybrid
AaBbCcDd

Heterosis

<https://plantlet.org/heterosis-breeding-being-better-than-parents/>

Table 10.1. Heterosis and dominance in relation to parental values.

Position and value of the parents	Value of the F ₁ hybrid	Phenomenon
	>10	Heterosis
Parent A(10)	10	Complete dominance
	<10 but >8	Partial dominance
(Mid-parent)	8	No dominance
	< 8 but >6	Partial dominance
Parent B (6)	6	Complete dominance
	< 6	Heterosis

Heterosis or Hybrid vigour:

- Hybrid vigour is synonym of Heterosis
- It is generally agreed that hybrid vigour describes only the superiority of hybrids over their parents, while Heterosis describes other situations as well

Luxuriance:

- The increased vigour and size of interspecific hybrids
- The principle difference between Heterosis and luxuriance: In reproductive ability of the hybrids
- **Heterosis**- increased fertility
- **Luxuriance**- expressed by interspecific hybrids that are generally sterile/ poorly fertile

Heterosis in cross and self pollinated species:

- Cross pollinated species: show Heterosis particularly when inbred lines are used as parents
- Ex. Bajra, Jowar, Cotton, Sunflower, Onion, Alfalfa
- Self pollinated species: show Heterosis, but the magnitude of Heterosis is generally smaller than that of cross pollinated species
- Ex. Tomato

Manifestation of Heterosis:

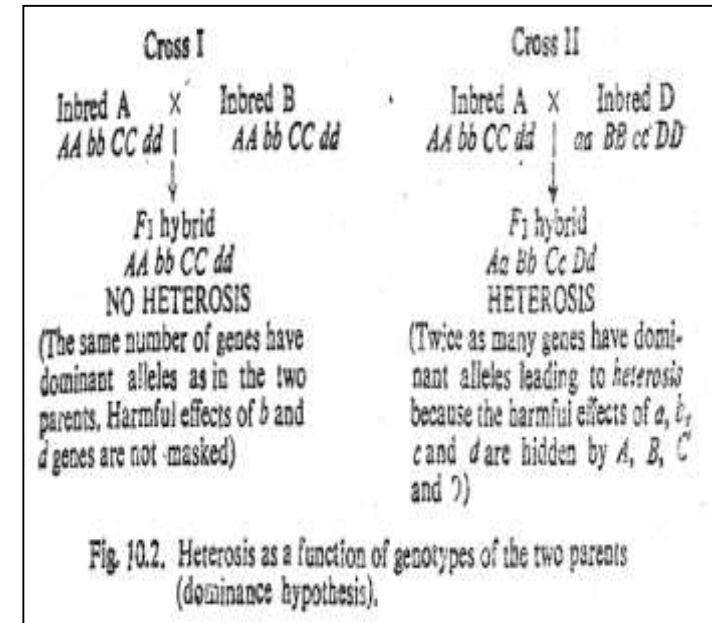
- Increased yield
- Increased reproductive ability
- Increase in size and general vigour
- Better quality
- Earlier flowering and maturity
- Greater resistance to disease and pests
- Greater adaptability
- Faster growth rate
- Increase in number of nodes, leaves and other plant parts

Genetic basis of Heterosis and inbreeding

- There are 2 main theories to explain Heterosis and consequently inbreeding depression:
- Dominance hypothesis
- Over dominance hypothesis

Dominance hypothesis

- Proposed by- Davenport 1908
- Later expanded by Bruce and by Keeble and Pellew in 1910
- Hypothesis- at each locus the dominant allele has favorable effect, while the recessive allele has unfavorable effect
- In heterozygous state, the deleterious effects of the recessive alleles are masked by their dominant alleles
- Thus the Heterosis results from the masking of harmful effects of recessive alleles by their dominant alleles
- Inbreeding depression- Produced by the harmful effects of recessive alleles which become homozygous due to inbreeding



Therefore,

- Heterosis is not a result of heterozygosity, it is the result of the prevention of expression of harmful recessives by their dominant alleles
- Inbreeding depression does not result from homozygosity per se, but from the homozygosity of recessive alleles which have harmful effects
- Objections:
- 1st objection relates to the failure in isolation of lines homozygous for all the dominant genes
- 2nd objection is directed at the symmetrical distribution in F₂

Over dominance hypothesis

- Proposed independently by East and Shull in 1908
- Sometimes known as single gene Heterosis, super dominance, cumulative action of divergent alleles and stimulation of divergent alleles
- Hypothesis- In Heterozygotes, at least some of the loci are superior to both the relevant homozygote's
- Thus heterozygote Aa would be superior to both the homozygote's AA and aa
- Consequently, heterozygosity is essential for and is the cause for Heterosis
- While homozygosity resulting from inbreeding produces inbreeding depression

Comparison between Dominance and over dominance hypotheses:

Similarities:

- Inbreeding would produce inbreeding depression
- Outcrossing would restore vigour and fertility
- The degree of Heterosis would depend upon the genotypes of the two parents. In general, the greater the genetic diversity between the parents, the higher the Heterosis

Differences:

- Heterozygotes are superior to the two homozygote's according to the over dominance hypothesis
- According to dominance hypothesis, they are as good as the dominant homozygote
- Therefore, inbreds as vigorous as the F1 hybrid can be isolated according to the dominance hypothesis
- Impossible to isolate according to over dominance hypothesis

Physiological basis of Heterosis

- Hybrid vigour resulted from large embryo and endosperm size of the hybrid seeds as compared to those of the inbreds
- Rate of growth in the seedlings stage may be expected to be greater in the hybrids than in the inbreds
- In 1952, Whaley concluded,
- The primary heterotic effect concerns growth regulators and enzymes
- Suggested that,
- Hybrid embryo would be able to mobilize stored food materials earlier than those of the inbreds due to a more efficient enzyme system
- This would lead to superiority of hybrids in the early seedling stages
- Biochemical level of Heterosis:
- Reduced amount of a single gene product
- Separate gene products by two alleles
- Combined gene product or the hybrid substance
- Effects in two different tissues

Commercial applications of Heterosis

- Used in the form of hybrid or synthetic varieties
- In several self-pollinated species, hybrid varieties have been commercially used
- Attempts made to utilize Heterosis in breeding of wheat and barley
- Some of the species where Heterosis has been commercially exploited are:
- **Crop species:** asexually propagated species, cross pollinated species
- Ex. Maize, jowar, bajra etc
- **Self pollinated crops:** Rice
- **Vegetable crops:** Tomato, Onion, Cucurbits, Brussels
- **Fruit trees:** Almost all fruit trees
- **Animals:** silk worm, poultry, cattle, swine

Crop improvement and breeding techniques

Crop improvement methods:

For selection of new varieties from mixed populations that have homozygous plants

Mass selection

Pureline selection

Pedigree method

For selection of segregating populations eg. F₂, F₃ etc

Bulk method

Backcross method

Mass selection

- Large number of plants of similar phenotype are selected and their seeds are mixed together to constitute a new variety
- Selection basis: Appearance or phenotype (plant height, ear type, grain colour, grain size, disease resistance, tillering ability, lodging resistance, shattering resistance)
- The population obtained from the selected plants would be more uniform than the original population
- Variety developed from mass selection would be the mixture of several purelines

Application of mass selection:

1. Purification of existing pureline varieties
2. Improvement of self pollinated crops
3. Improvement of Desi or local varieties

Procedure:

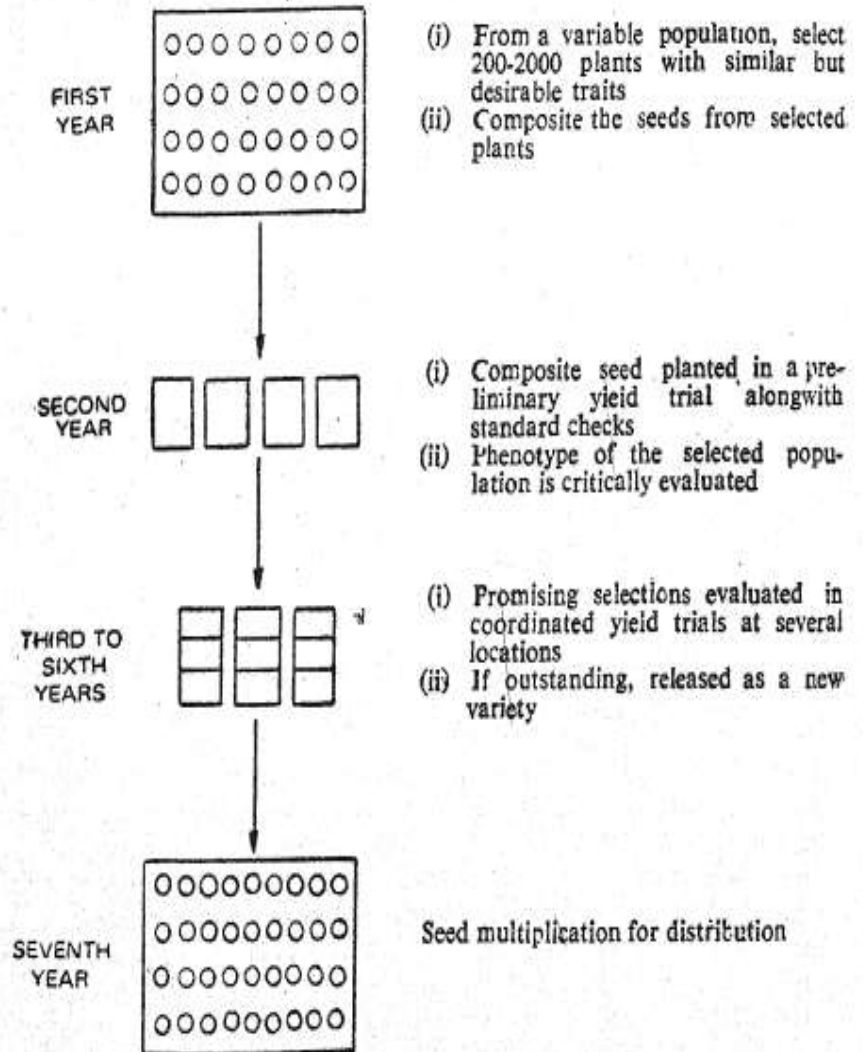


Fig. 11.1. Mass selection in self-pollinated crops is used to develop new varieties. For maintaining the purity of pureline varieties, operations of the first year may be repeated every year or after every few years.

For mass selection,

Merits:

- Varieties developed through mass selection are likely to be more widely adapted than purelines
- Reduced time and cost needed for developing a new variety
- Retains considerable genetic variability
- Breeder friendly method

Demerits:

- Varieties developed through mass selection show variation and are not as uniform as pureline varieties
- Improvement through mass selection is generally less than that through pureline selection
- In the absence of progeny test, it is impossible to determine if the selected plants are homozygous
- Due to popularity of pureline varieties, mass selection is not commonly used in the improvement of self pollinated crops
- Varieties developed by mass selection are more difficult to identify than purelines in seed certification programme
- Mass selection is limited by the fact that it cannot generate variability

Pureline selection

- Large number of plants are selected from a self-pollinated crop and are harvested individually, their individual progenies are evaluated and the best progeny is released as a pureline variety
- Pureline selection is also known as individual plant selection
- Pureline variety- a variety obtained from a single homozygous plant of a self pollinated crop
- A variety developed through pureline selection would be a pureline variety
- In self pollinated crops, pureline varieties are far more common than mixtures of purelines

Characteristics of purelines:

- All the purelines within a pureline have the same genotype
- The variation within a pureline is environmental and non heritable
- Purelines become genetically variable with time

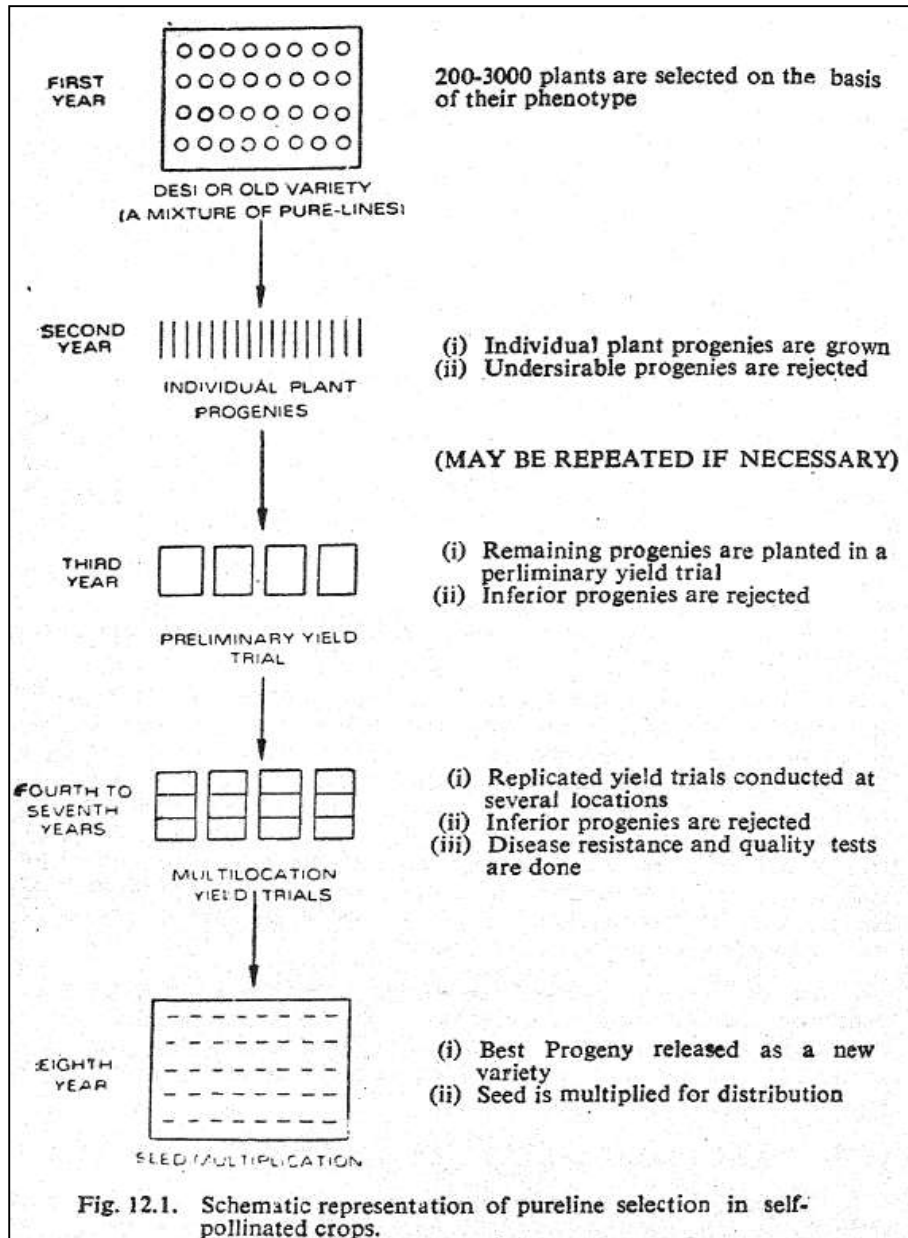
Uses of pureline:

- As a variety
- As parents in a hybridization programme
- In studies on mutation

Applications of pureline selection:

- Improvement of local variety
- Pureline selection in introduced varieties
- Improvements of old pureline varieties
- Selection for a new characteristics in a pureline
- Selection in the segregating generations from crosses

Procedure:



Fore pureline selection,

Merits:

- Achieves maximum possible improvement over the original variety
- Varieties are extremely uniform since all the plants in the variety have the same genotype
- Variety can be identified easily in seed certification programme

Demerits:

- Variety developed by pureline selection generally do not have a wide adaptation and stability in production possessed by the local / Desi varieties
- Procedure requires more time, space and more expensive yield trials
- Upper limit on the improvement is set by the genetic variation present in the original population
- Breeder has to devote more time to pureline selection

Table 12.1. Comparison between pureline and mass selections.

<i>Pureline selection</i>	<i>Mass selection</i>
1. The new variety is a pureline.	The new variety is a mixture of purelines.
2. The new variety is highly uniform. In fact, the variation within a pureline variety is purely environmental.	The variety has genetic variation for quantitative characters, although it is relatively uniform in general appearance.
3. The selected plants are subjected to progeny test.	Progeny test is generally not carried out.
4. The variety is generally the best pureline present in the original population. The pureline selection brings about the greatest improvement over the original variety.	The variety is inferior to the best pureline because most of the purelines included in it will be inferior to the best pureline.
5. Generally, a pureline variety is expected to have a narrower adaptation and lower stability in performance than a mixture of purelines.	Usually the variety has a wider adaptation and greater stability than a pureline variety.
6. The plants are selected for their desirability. It is not necessary that they should have a similar phenotype.	The selected plants have to be similar in phenotype since their seeds are mixed to make up the new variety.
7. It is more demanding because careful progeny tests and yield trials have to be conducted.	If a large number of plants are selected, extensive yield trials are not necessary. Thus it is less demanding on the breeder.
8. Generally, 9-10 years are required to develop a new variety.	Generally, 5-7 years are required to develop a new variety.
9. Selection within a pureline variety is ineffective unless it has become genetically variable.	Selection within a variety developed by mass selection is effective since it has genetic variation.
10. The produce of a pureline variety is uniform in quality.	The produce is generally not uniform since different purelines making up the variety may differ in the quality of their gains etc.
11. The variety is easily identified in seed certification programmes.	The variety is relatively difficult to identify in seed certification programmes.
12. Pureline selection is used in self-pollinated and often cross-pollinated crops.	Mass selection is used in both self- and cross-pollinated crops.

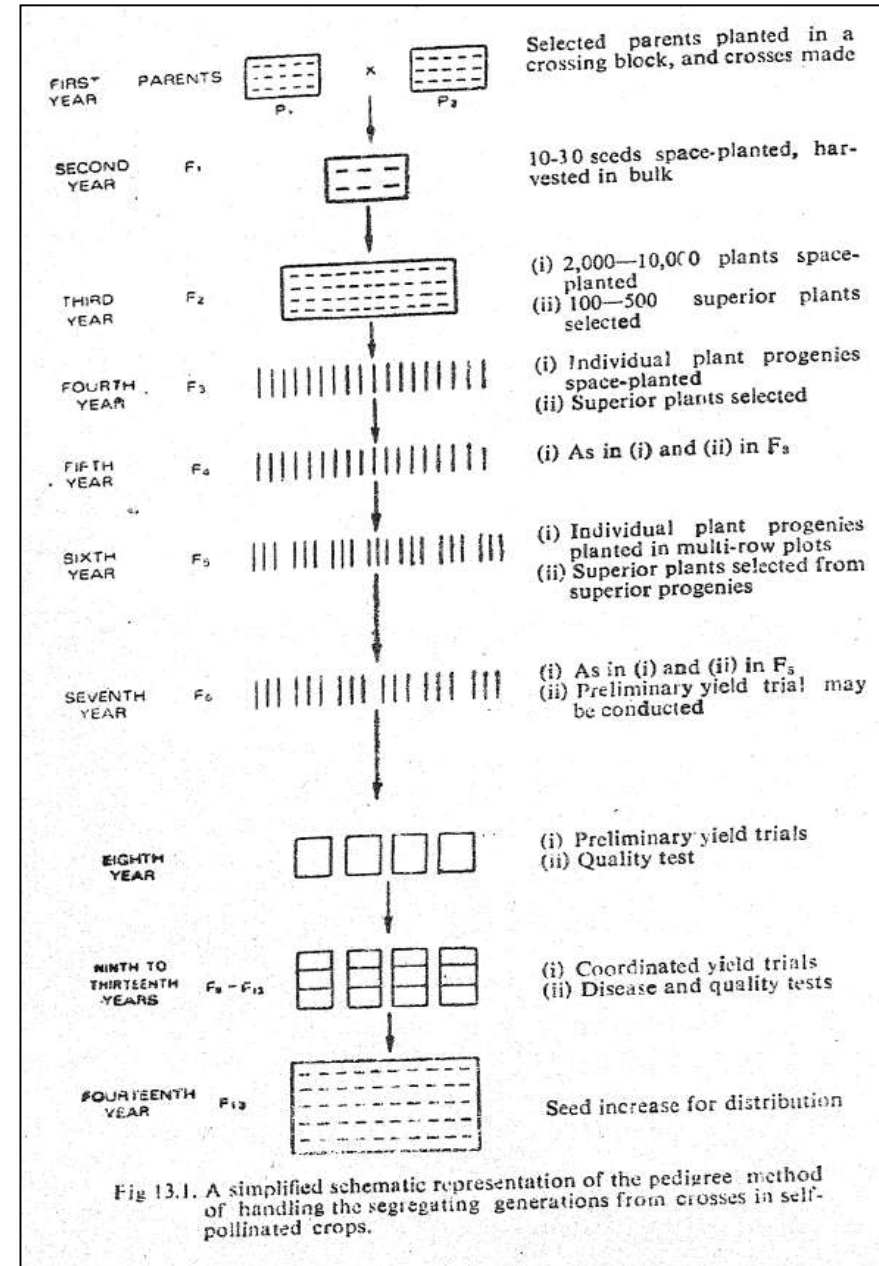
Pedigree method

- Method used for handling the segregating generations
- To develop pureline varieties
- Individual plants are selected from F₂ and subsequent generations and their progenies are tested
- A record of all the parent-offspring relationship is kept- **pedigree record**
- **Pedigree**- a description of the ancestors of an individual and it generally goes back to some distant ancestor or ancestors in the past
- Helpful in finding out if two individuals are related by descent or not

Application of pedigree method:

- Used for selection from segregating generations of crosses in self-pollinated crops
- Used to correct some specific weaknesses of an established variety (combination breeding)
- Useful in selection of new superior recombination types
- Suitable for improving specific characteristics such as disease resistance, plant height, maturity time
- Transgressive segregants can be recovered (transgressive breeding)

Procedure:



For pedigree method,

Merits:

- Gives maximum opportunity for breeder to use his skill and judgment for the selection of plants
- Well suited for improvement of characters which can be easily identified and are simply inherited
- Transgressive segregations for yield and other quantitative characters may be recovered
- Takes less time than bulk method to develop a new variety
- Able to obtain information about inheritance of qualitative characters from pedigree record
- Plant and progenies with visible defects and weaknesses are eliminated at an early stage in breeding programme

Demerits:

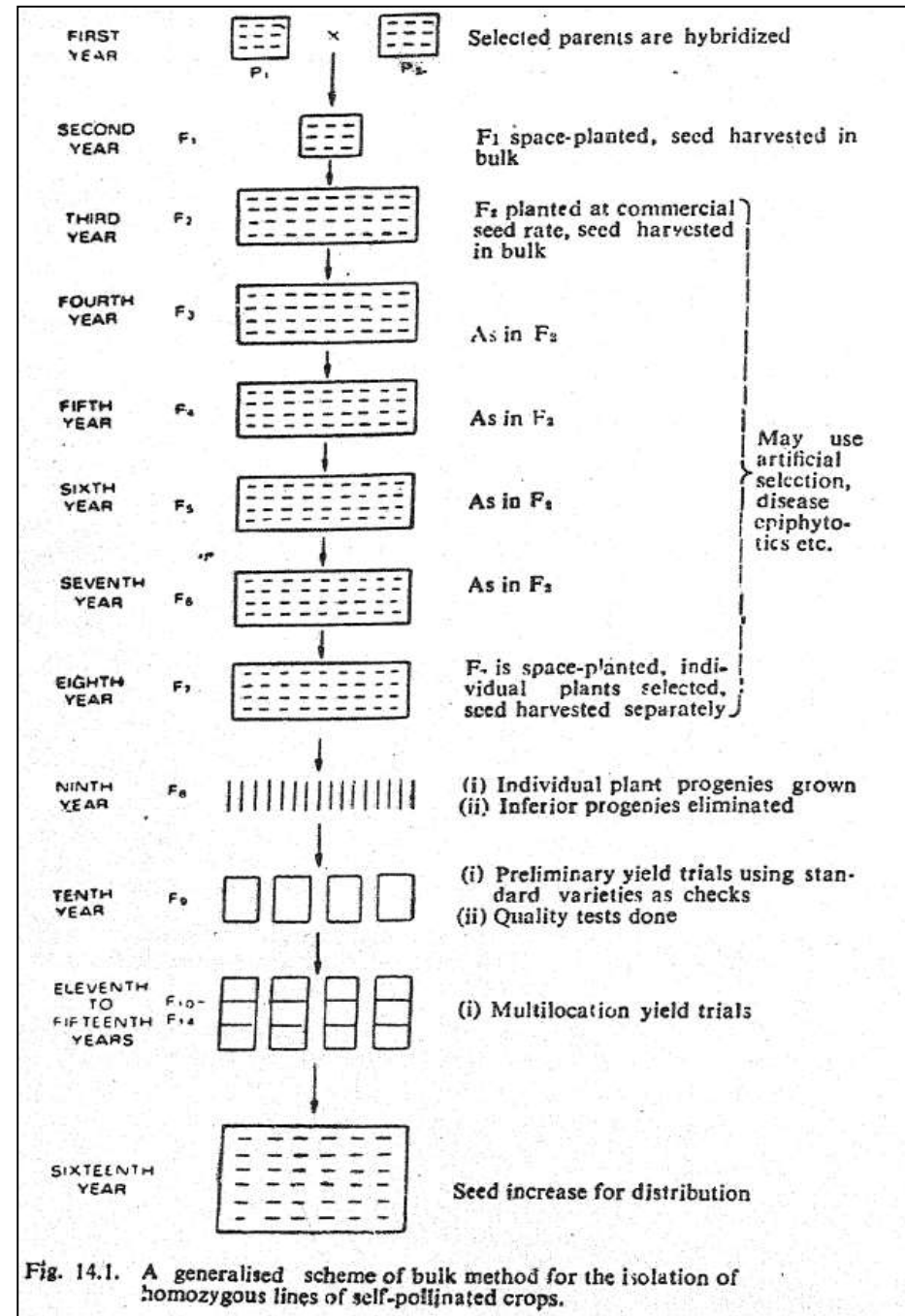
- Maintenance of pedigree record takes up valuable time
- Breeders would not be able to handle many crosses according to the pedigree method
- Success of this method is largely depended on the skill of the breeder
- Selection of yield in F₂ and F₃ is ineffective

Bulk method

- Also known as mass method / population method of breeding
- F₂ and Subsequent generations are harvested in mass or as bulks to raise the next generation
- At the ending of bulking period, individual plants are selected and evaluated in a similar manner as pedigree method

Applications of bulk method:

- Isolation of homozygous lines
- Waiting for the opportunity for selection
- To provide opportunity for natural selection to change the composition of the population



Merits:

- Simple, convenient and inexpensive
- Artificial and natural disease, Epiphytotic, winter killing etc. eliminate the undesirable types and increase frequency of desirable types
- Isolation of desirable types thus becomes easier
- Natural selection increases the frequency of superior types in the population
- Breeder is free to concentrate more on other breeding projects
- No pedigree record is to be kept, which saves time and labour
- Transgressive segregants are more likely to appear and increase due to natural selection
- Artificial selection may be practiced to increase the frequency of desirable types
- Suitable for studies on the survival of genes and genotypes in populations

For bulk method,**Demerits:**

- Takes much longer time to develop a new variety
- In short term bulks, natural selection has little effect on the genetic composition of populations. But short term bulks are useful for the isolation of homozygous lines and for specific objectives as in Harlan's Mass pedigree method
- Provides little opportunity for the breeder to exercise his skills or judgment in selection
- A large number of progenies have to be selected at the end of the bulking period
- Information on the inheritance of characters cannot be obtained
- Natural selection may act against the agronomically desirable types in some cases

Table 14.1. Comparison between bulk and pedigree methods.

<i>Pedigree method</i>	<i>Bulk method</i>
1. Individual plants are selected in F_2 and the subsequent generations and individual plant progenies are grown.	F_2 and the subsequent generations are maintained as bulks.
2. Artificial selection, artificial disease epidemics etc. are an integral part of the method.	Artificial selection, artificial disease epiphytotics etc. may be used to assist natural selection. In certain cases, artificial selection may be essential.
3. Natural selection does not play any role in the method.	Natural selection determines the composition of the populations at the end of the bulking period.
4. Pedigree records have to be maintained which is often time consuming and laborious.	No pedigree records are maintained.
5. It generally takes 14-15 years to develop a new variety and to release it for cultivation.	It takes much longer for the development and release of a variety. The bulk population has to be maintained for more than 10 years for natural selection to act.
6. Most widely used breeding method.	Used only to a limited extent.
7. It demands close attention from the breeder from F_2 onward as individual plant selections have to be made and pedigree records have to be maintained.	It is simple, convenient and inexpensive and does not require much attention from the breeder during the period of bulking.
8. The segregating generations are space-planted to permit individual plant selection.	The bulk populations are generally planted at commercial planting rates.
9. The size of population is usually smaller than that in the case of bulk method.	Large populations are grown. This and natural selection are expected to increase the chances of the recovery of transgressive segregants.

Backcross method

Backcross- cross between a hybrid (F1 or a segregating generation) and one of its parents

- The hybrid and the progenies in the subsequent generations are repeatedly backcrossed to one of the parents
- As a result the genotype of backcross progeny becomes increasingly similar to that of the parent to which it is backcrossed

Objective:

- To improve one or two specific defects of a high yielding variety, which is well adapted to the area and has other desirable Characteristics

Requirements for Backcross programme:

- A suitable recurrent parent must be available, which lacks in one or two characteristics
- A suitable donor parent must be available. The donor parent should have the character or the characters to be transferred in a highly intense form
- The characters to be transferred must have high heritability
- 6-7 backcrosses are sufficient for the purpose

Application of backcross method:

- Intervarietal transfer of simply inherited characters
- Intervarietal transfer of quantitative characters
- Interspecific transfer of simply inherited characters
- Transfer of cytoplasm
- Transgressive segregation
- Production of isogenic lines
- Germplasm conversion

Procedure:

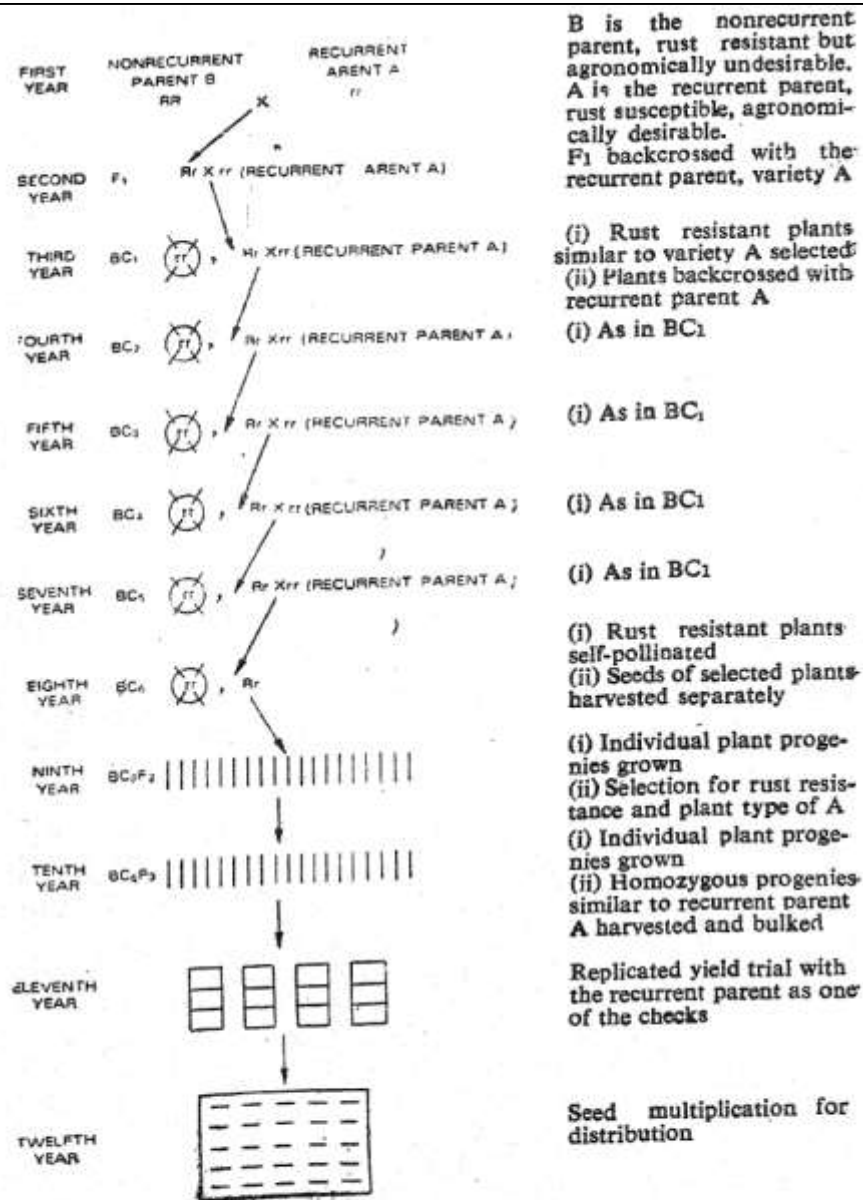


Fig. 15.2. A generalised scheme for the transfer of a dominant gene for disease resistance through the backcross method in a self-pollinated species.

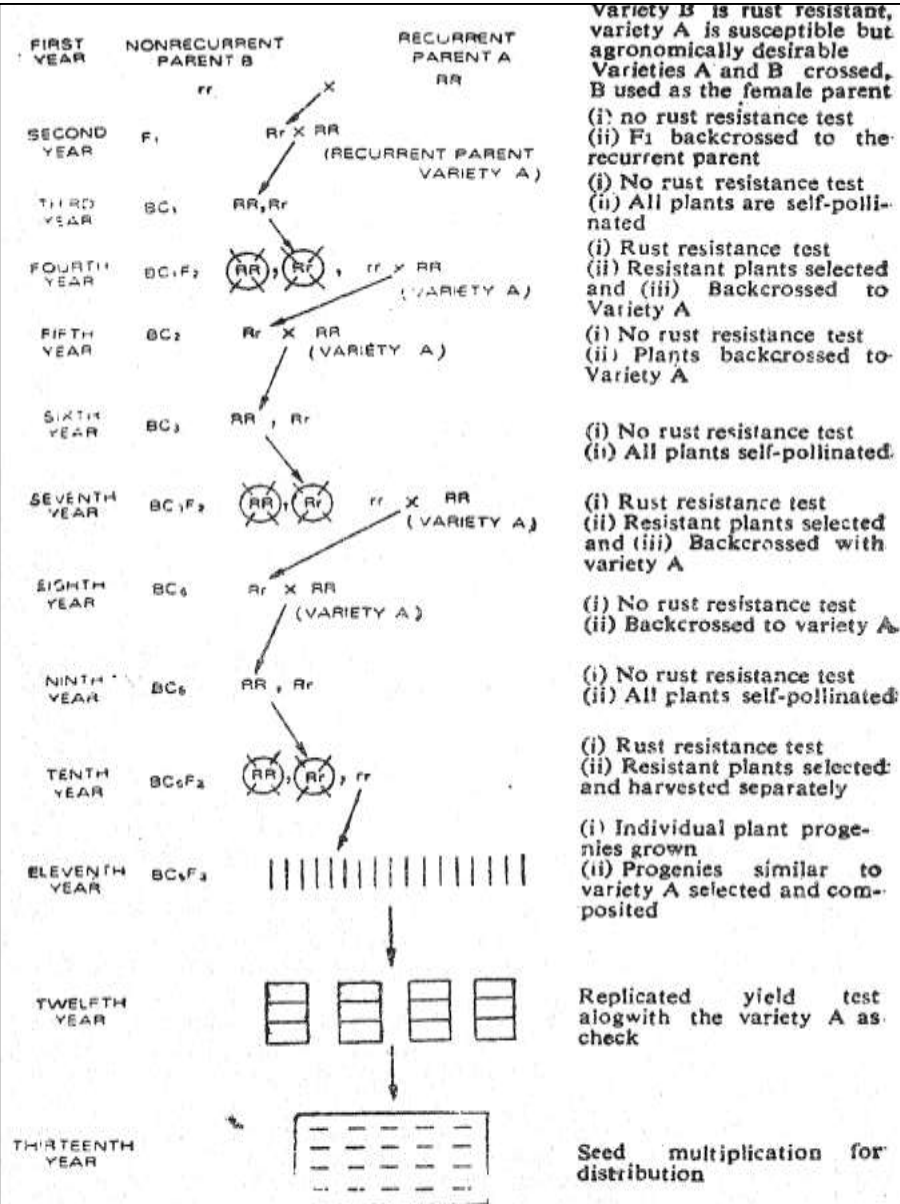


Fig. 15.3. A generalised scheme for the transfer of a recessive gene for disease resistance through the backcross method in a self-pollinated crop.

For backcross method,**Merits:**

- Outcome of backcross programme is known beforehand and it can be reproduced any time in the future
- Performance of recurrent parent is already known, therefore it is not necessary to test the variety developed by backcross method
- Backcross method is not dependent upon environment, except for that needed for the selection of the characters under transfer
- Much smaller populations are needed in the backcross method
- Defects can be removed without affecting the performance and adaptability of a variety
- The only method for interspecific gene transfers
- It may be modified so that transgressive segregation may occur for quantitative characters

Demerits:

- New variety generally cannot be superior to the recurrent parent
- Undesirable genes closely linked with the gene being transferred may also be transmitted to the new variety
- Hybridization has to be done for each backcross leading to high time consumption and costly
- By the time the backcross programme improves it, the recurrent parent may have been replaced by other varieties superior in yielding ability and other characteristics

Table 15.2. Comparison between backcross and pedigree methods

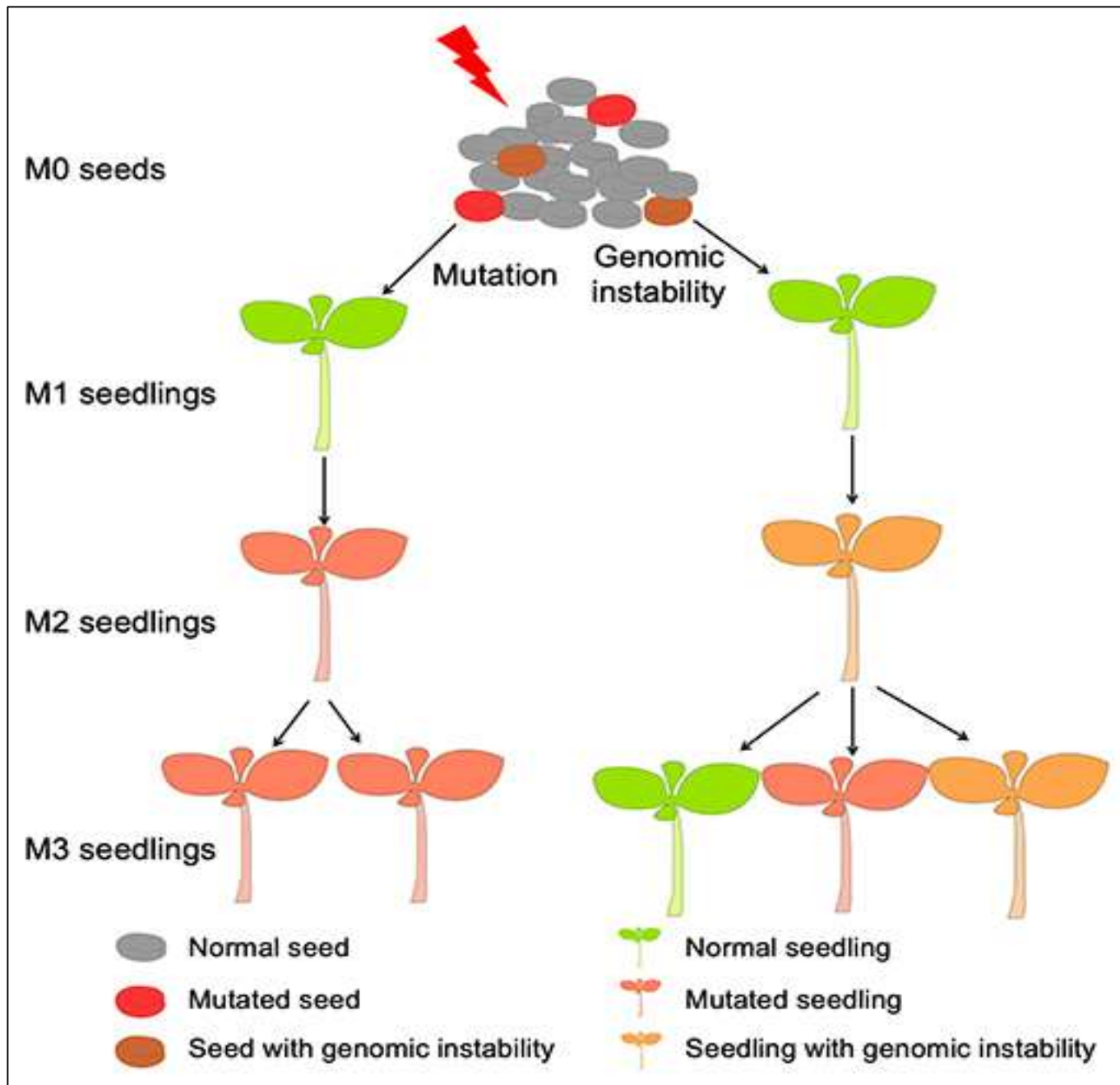
<i>Pedigree method</i>	<i>Backcross method</i>
1. F_1 and the subsequent generations are allowed to self-pollinate.	F_1 and the subsequent generations are backcrossed to the recurrent parent.
2. The new variety developed by this method is different from the parents in agronomic and other characteristics.	The new variety is identical with the recurrent parent, except for the character under transfer.
3. The new variety has to be extensively tested before release.	Usually extensive testing is not necessary before release.
4. The method aims at improving the yielding ability and other characteristics of the variety.	The method aims at improving specific defects of a well adapted, popular variety.
5. It is useful in improving both qualitative and quantitative characters.	Useful for the transfer of both quantitative and qualitative characters provided they have high heritability.
6. It is not suitable for gene transfer from related species and for producing substitution or addition lines.	It is the only useful method for gene transfers from related species and for producing addition and substitution lines.
7. Hybridization is limited to the production of the F_1 generation.	Hybridization with the recurrent parent is necessary for producing every backcross generation.
8. The F_2 and the subsequent generations are much larger than those in the backcross method.	The backcross generations are small and usually consist of 20-100 plants in each generation.
9. The procedure is the same for both dominant and recessive genes.	The procedures for the transfer of dominant and recessive genes are different.

Role of mutation in crop improvement

Mutation- sudden heritable changes in a characteristics of an organism / plant

May be result of change in gene, a change in chromosome that involve several genes or a change in a plasmid

- Mutations produced by changes in the base sequences of genes (as a result of base pair transition or Transversion, deletion, duplication or inversion) -**point/ gene mutations**
- Mutations produced by changes in chromosome structure, chromosome number-**chromosomal mutations**
- When mutant characters shows cytoplasmic or extra nuclear inheritance-**cytoplasmic mutations**
- Mutations occurring in bud or somatic tissues- **bud mutations/ somatic mutations**
- **Spontaneous and induced mutations**
- Mutations occurring in natural population (without any treatment by man) at a low rate-**spontaneous mutations**
- Mutations occurring artificially, induced by treatment of certain physical or chemical agents- **induced mutations** (agents causing mutations- **mutagen**)
- The utilization of induced mutations for crop improvement- **mutation breeding**



Mutagens

Physical mutagens

Chemical mutagens

Ionizing radiations

Non ionizing radiations

Particulate radiations

α Rays, β rays,
fast neutrons,
thermal neutrons

Non particulate radiations

UV radiations

- **Alkylating agents-** Sulphur mustards, nitrogen mustards, Epoxides, ethylene-imines, sulphates, sulphonates, Diazoalkanes, nitroso compounds
- **Acridine dyes-** Acriflavine, proflavine, acridine orange, acridine yellow, ethidium bromide
- **Base analogs-** 5-Bromouracil, 5-Chlorouracil
- **Others-** nitrous acid, hydroxylamine, sodium azide

Characteristics of mutations:

- Induced mutations rarely produce new alleles
- They produce alleles which are already known to occur spontaneously
- Mutations are generally recessive but dominant mutations also occur
- Mutations are generally harmful to organisms
- Mutations are random
- Mutations are recurrent
- Induced mutations commonly show pleiotropy often due to mutations in closely linked genes

Effects of mutations:

- Lethal- lethal mutations kill each and every individual that carries them in the appropriate genotype
- Sublethal and sub vital- mutations reduce viability, but do not kill all the individuals carrying them
- Vital- mutations do not reduce viability of the individuals carrying them

Procedure:

- Selection of the variety for mutagen treatment
- Selection of part of plant to be treated
- Dose of mutagen
- Giving the mutagen treatment
- Handling of the mutagen- treatment population

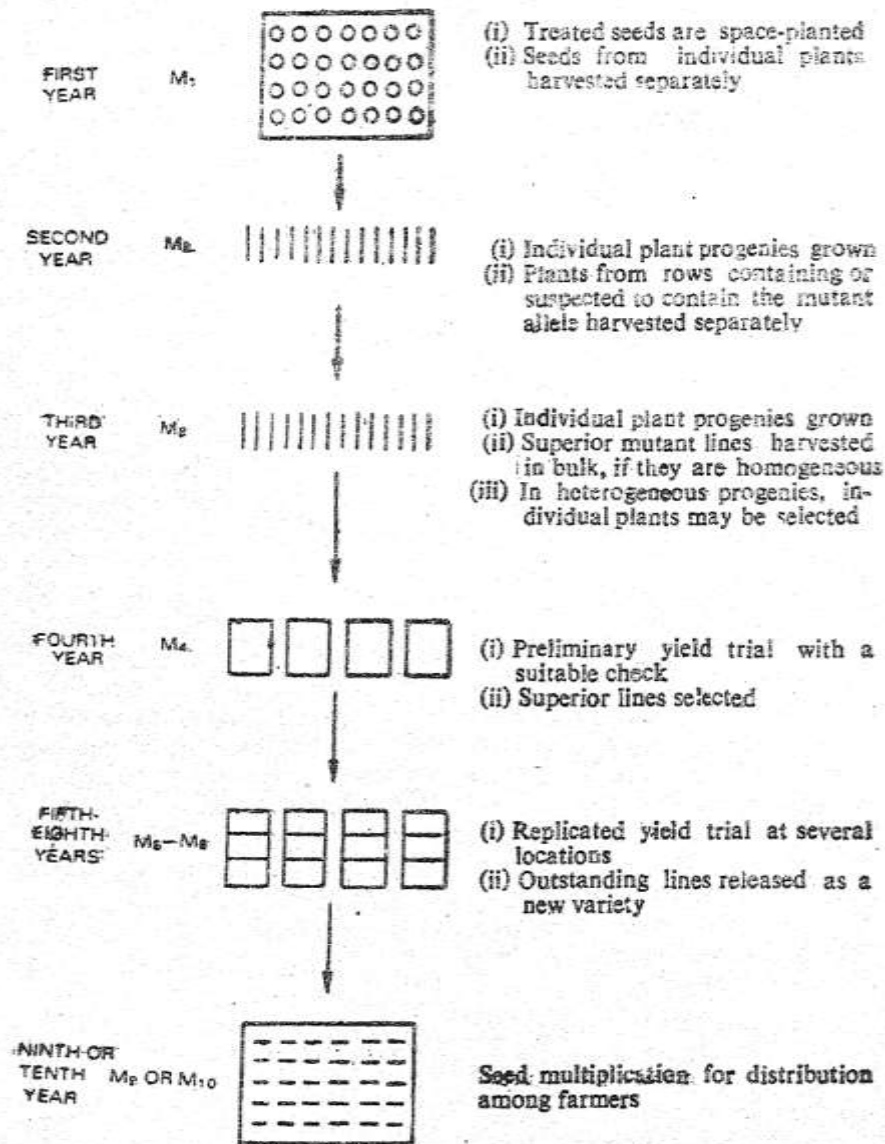


Fig. 23.6. A generalised scheme for mutation breeding for an oligogenic trait ; the mutant allele is recessive.

For oligogenic traits

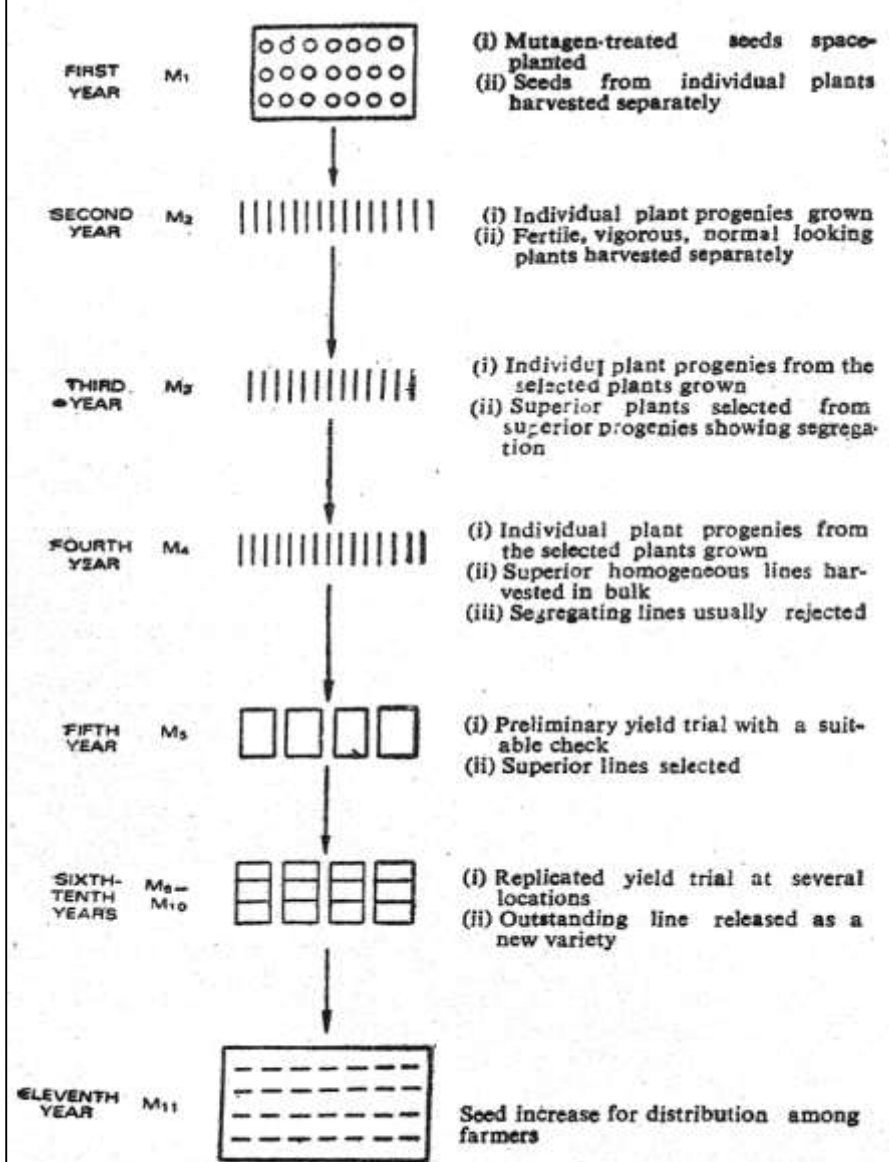


Fig. 23.7. A generalised scheme for mutation breeding for polygenic traits.

For polygenic traits

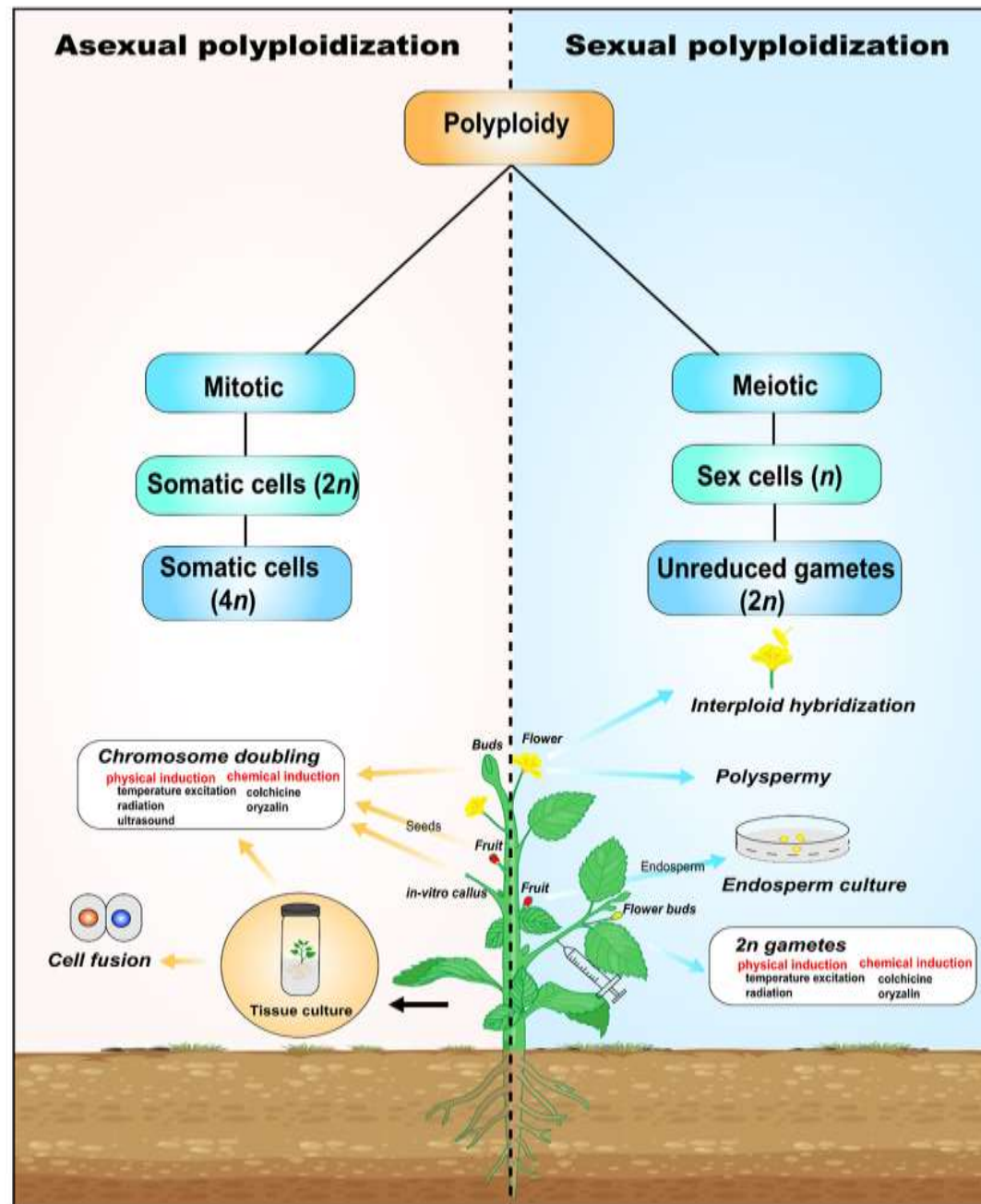
Application of mutation breeding:

- Mutation breeding relieves the complete dependence of breeders on the natural germplasm
- Useful in improving specific characteristics of a well adapted high yielding variety
- In self pollinated species, mutagenesis is useful in improving the specific characteristics of otherwise adapted and superior varieties
- Mutagenesis has been successfully used to improve various quantitative characters, including yield
- F1 hybrids from Intervarietal crosses may be treated with mutagens in order to increase genetic variability by inducing mutations and to facilitate recombination of linked genes
- Irradiation of interspecific (distant) hybrids has been done to produce translocations

Limitations of mutation breeding:

- The frequency of desirable mutations is very low about 0.1 percent of the total mutations
- The breeder has to screen large populations to select desirable mutations
- Desirable mutations are commonly associated with undesirable side effects due to other mutations, chromosomal aberrations etc.
- Most of mutations are recessive, detection of recessive mutations is almost impossible in clonal crops and is difficult in polyploid species

Polyploidy in plant breeding



Polyploidy

- The chromosome number of an organism is an exact multiple of the basic or genomic number
- When all genomes present in a polyploid species are identical, it is known as **autopolyploid**
- If 2 or more distinct genomes are present, it is known as **allopolyploid**
- Individuals carrying chromosome numbers other than the diploid ($2x$ and not $2n$) number are known as heteroploids and the situation is known as heteroploidy
- **Aneuploidy**- the change in chromosome number may involve one or few chromosome in the genome

Term of Aneuploidy	Type of change	Symbol
Nullisomic	One chromosome pair missing	$2n-2$
Monosomic	One chromosome missing	$2n-1$
Double Monosomic	One chromosome from each of 2 different chromosome pairs missing	$2n-1-1$
Trisomic	One chromosome extra	$2n+1$
Double Trisomic	One chromosome from each of two different chromosome pair extra	$2n+1+1$
Tetrasomic	One chromosome pair extra	$2n+2$

Origin and production of aneuploids:

- Spontaneous
- Triploid plants
- Asynaptic and desynaptic plants
- Translocation heterozygotes
- Tetrasomic plants

Morphological features and cytological features of aneuploids

- Aneuploids are generally weaker than diploids
- **Monoploids**- do not survive in diploid species
- **Nullisomics**- do not survive in some polyploid species
- Cytology:
- Nullisomics- show regular bivalent formation and chromosome distribution producing gametes with $n-1$ chromosomes
- **Tetrasomics**- relatively less regular, form one quadrivalent at metaphase I which often separates 2:2 at anaphase I
- **Monosomics**- One chromosome does not have a pair and remains as a univalent at metaphase I. At anaphase I, the univalent may move to one of the two poles
- **Trisomics**- extra chromosome often forms a trivalent with the other two homologous chromosomes, or may remain as a univalent

Applications of aneuploids in crop improvement

- Useful in studies on the effects of loss or gain of an entire chromosome or a chromosome arm on the phenotype of the individual
- Useful in locating a linkage group and a gene to a particularly useful in identifying the chromosomes involved in translocation
- Useful in production of substitution lines

Autopolyploidy

- When all genomes present in a polyploid species are identical, it is known as autopolyploid and the phenomenon is Autopolyploidy

Origin and production of autopolyploid

- Spontaneous
- Production of adventitious buds
- Physical mutagens
- Regeneration in vitro
- Colchicine treatment

Terms	Type of change	Symbol
Auto triploid	3 genomes	3x
Auto Tetraploid	4 genomes	4x
Auto Pentaploid	5 genomes	5x
Auto Hexaploid	6 genomes	6x
Auto Octaploid	8 genomes	8x

Morphological and cytological features of autopolyploid

- Autopolyploids have larger cell size than diploids
- Pollen grains of Autopolyploids are generally larger than those of corresponding diploids
- Autopolyploids generally slower in growth and later in flowering
- Autopolyploids usually have larger and thicker leaves, larger flowers and fruits
- Autopolyploids generally show reduced fertility due to irregularities during meiosis
- Cytology:
- **Monoploids**- chromosomes do not pair and their distribution at anaphase I is random leading to and almost complete sterility
- **Triploids**- Variable number of trivalents, bivalents and univalents are produced

Applications of Autopolyploids in crop improvement

- Used for developing homozygous diploid lines
- Useful in the isolation of mutants because the mutant alleles (even if it is recessive) expresses itself in M1 due to a single dose of the gene in somatic tissues
- Used in induction and formation of embryoid production
- Production of seedless watermelons, triploid sugar beets etc.
- Used to overcome self incompatibility in certain cases, eg. Some genotypes of tobacco and white clover

Allopolyploidy

- If 2 or more distinct genomes are present, it is known as allopolyploid
- Ex. Triticale, Raphanobrassica

Origin and production of allopolyploids

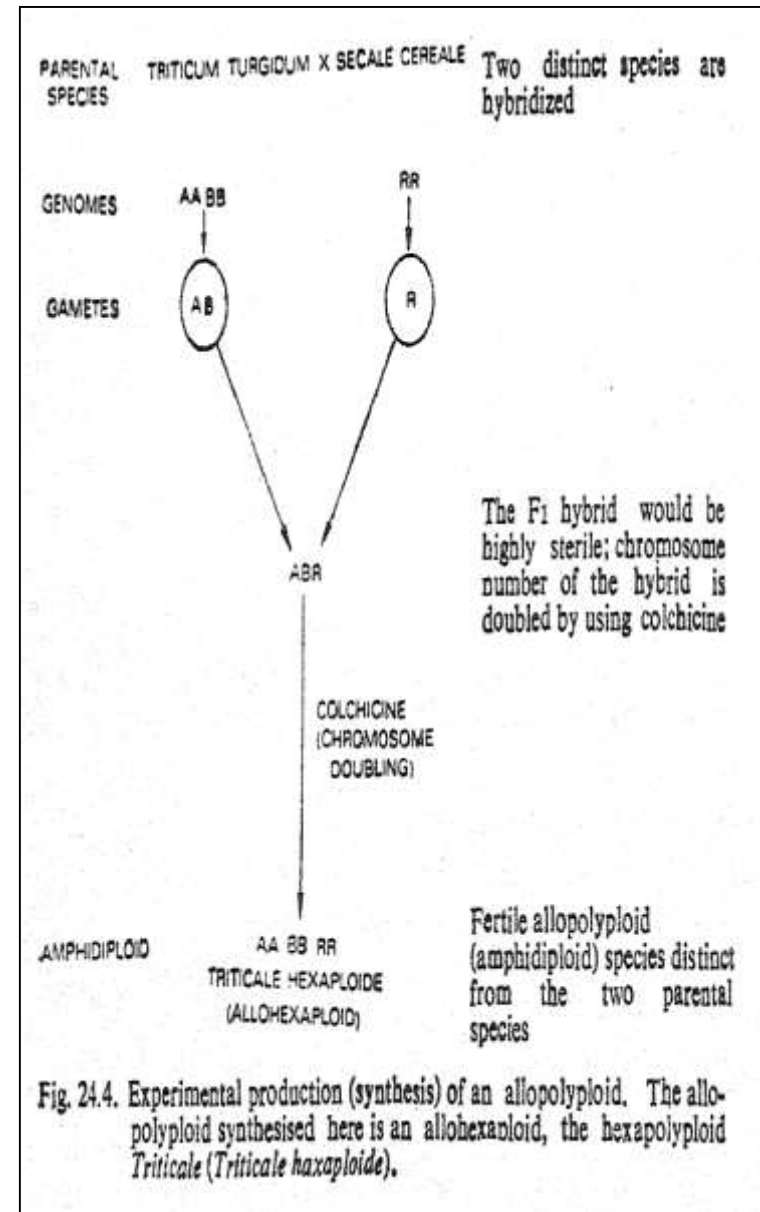
- Chromosome doubling in F1 hybrids between two distinct species belonging to same genus or to different genera
- Irregular meiotic cell division
- Synthetic allopolyploids (by colchicine treatment or some other agent)

Morphological and cytological features of allopolyploids

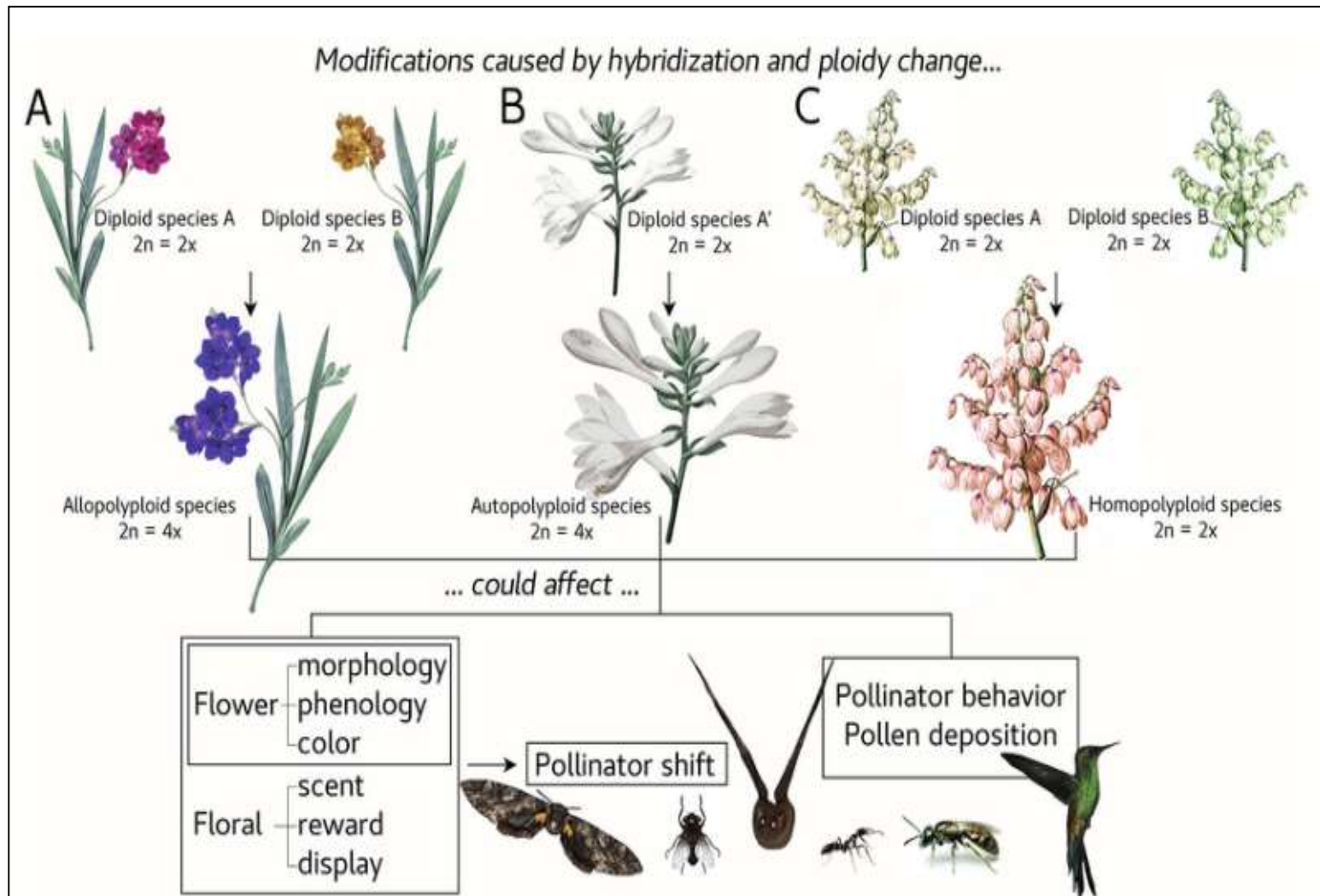
- More vigorous than diploids
- Irregular chromosome pairing
- Harder than the parental species
- They are apomictic
- Sterile

Application of allopolyploids in crop improvement

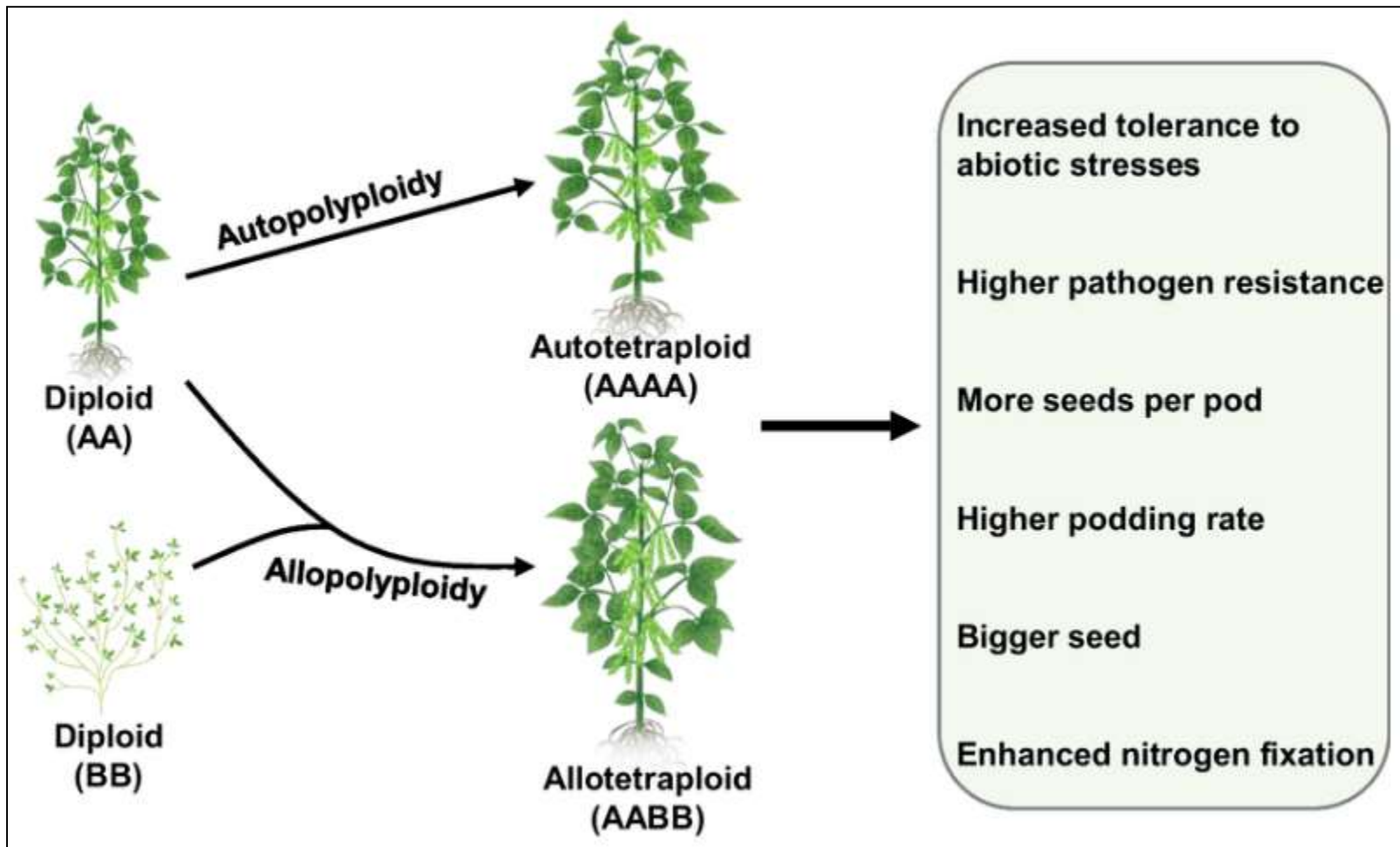
- Utilization as bridging species
- Creation of new crop species
- Widening the genetic base of existing allopolyploids



Production of allopolyploids

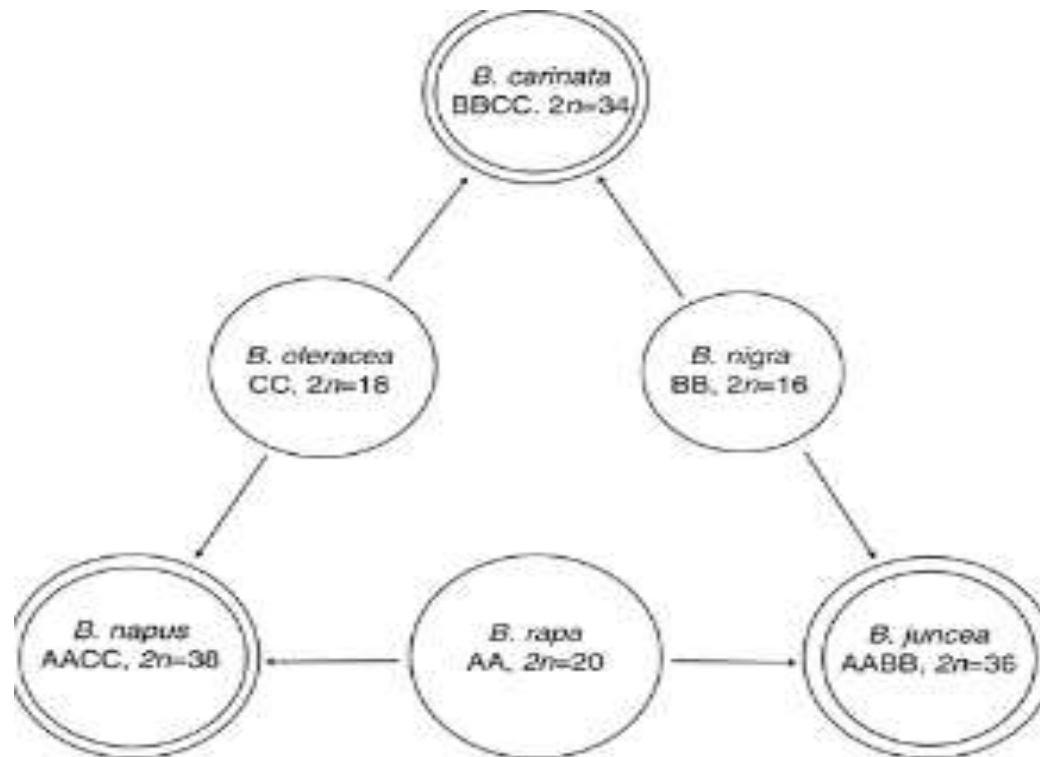


A. Allopolyploidy, B. Autopolyploidy, C. Homoploidy. Below follow the main floral traits affected by hybridization and polyploidy and the main traits affected in the pollinator taxa (in the absence of pollinator shift). Figures were modified from Freepik (<https://www.freepik.com/>), except by hummingbird, bat, and hawkmoth photos, which were supplied by F.W. Amorim.



Development of autotetraploid and allotetraploid soybeans. Autopolyploidy and allopolyploidy have the potential to optimize multiple traits in soybean, including tolerance to abiotic stresses, pathogen resistance, seeds per pod, podding rate, seed weight, and nitrogen fixation efficiency

Distant hybridization in plant breeding



Distant hybridization

- Hybridization between individuals from different species, belonging to the same genus or to different genera
- Such crosses are known as distant crosses or wide crosses

Barriers to production of distant hybrids:

- Failure of zygote formation
- Failure of zygote development
- Lethal genes
- Genotypic disharmony between the two parental genomes
- Chromosome elimination
- Incompatible cytoplasm
- Endosperm abortion
- Failure of hybrid seedling development

Techniques for production of distant hybrids:

- Determining the barriers
- Measures to overcome these barriers (stigma cutting off to facilitate crossing, using growth regulators, using of bridge species, doubling of chromosome number of polyploid species, embryo culture technique)

Applications of distant hybridization in crop improvement :

- Production of alien- addition lines
- Production of alien- substitution lines
- transfer of small chromosome segments
- Genes affecting a variety of characters have been transferred from wild relatives through distant hybridization
- Utilization as new variety
- Transfer of cytoplasm

Role of biotechnology in crop improvement

Biotechnology in plant breeding

- Enables scientists to develop crops with improved traits such as increased yield, disease resistance and drought tolerance
- It involves in vitro techniques which is useful to the cultivation of plant organs, tissues or cells in the test tubes within artificial media

Need of biotechnology in plant breeding

- Production of purelines or inbreds
- Production of haploids through distant crosses or through pollen culture followed by chromosome doubling
- Recovery of embryo
- Recovery of hybrid plants

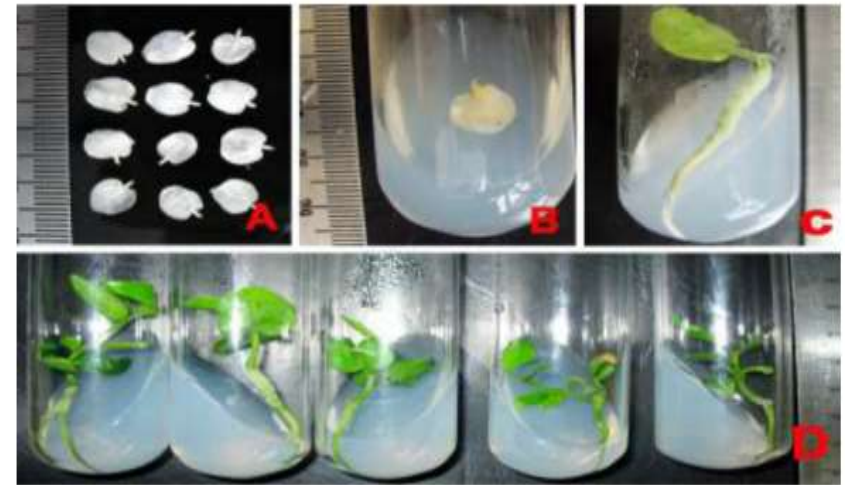
Application of biotechnology in crop improvement

- Genetically modified crops
- Gene editing technologies
- Biofertilizers and Biopesticides preparation
- Marker assisted selection (MAS)
- Increased crop productivity
- Environmental sustainability
- Improved nutritional contents
- Climate resilience

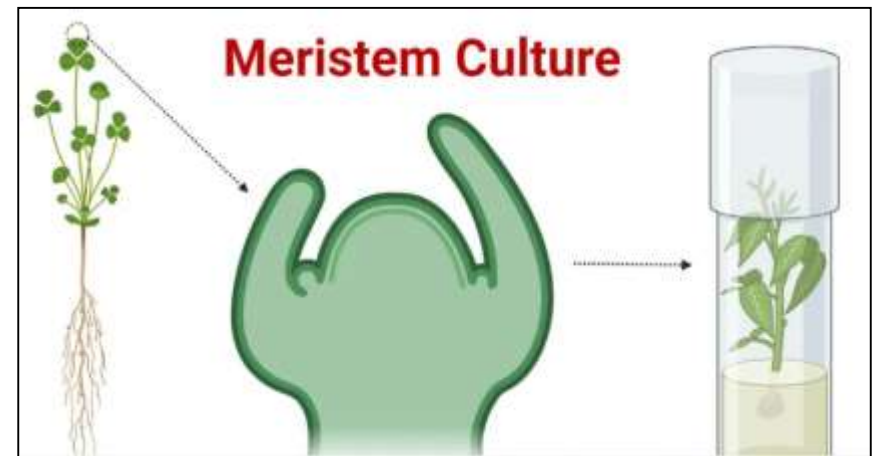


Classification of invitro techniques used in biotechnology

1. **Embryo culture** – removal of young embryos from developing seeds and growing them in suitable culture media.
 - Useful in recovery of hybrid plants from distant crosses, shortening of breeding cycle and overcoming dormancy
2. **Meristem culture** –shoot apical meristem along with some surrounding tissue is grown in vitro.
 - Used for clonal propagation and recovery of virus free plants and is potentially useful in germplasm exchange and long term storage of germplasm through freeze-preservation



https://www.researchgate.net/figure/n-vitro-zygotic-embryo-culture-and-micropropagation-of-Drypetes-roxburghii_fig1_262530817



<https://microbenotes.com/meristem-culture/>

3. Pollen culture –anthers or isolated pollen grains in vitro.

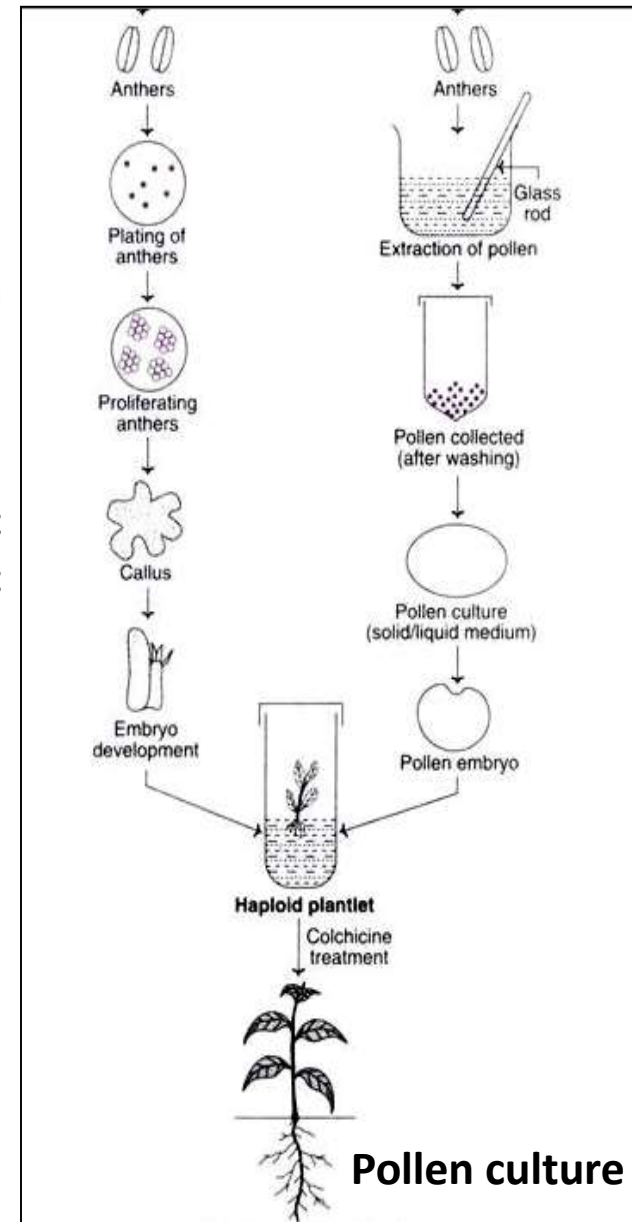
- Used to obtain haploid plants which are being used in tobacco and rice improvement

4. Tissue culture- Growing plant cells as relatively unorganized masses of cells on the agar medium (callus culture) or as a suspension of free cells and small masses in a liquid medium (Suspension culture).

- Used to vegetative multiplication of many species, recovery of virus-free plants, production of somatic hybrids, organelles and cytoplasm transfer, genetic transformation and germplasm conservation



https://www.firsthope.co.in/types-of-plant-tissue-cultures/#google_vignette



https://www.biologydiscussion.com/plants/haploid-plants/production-of-haploid-plants-with-diagram/10700#google_vignette

Genetic engineering

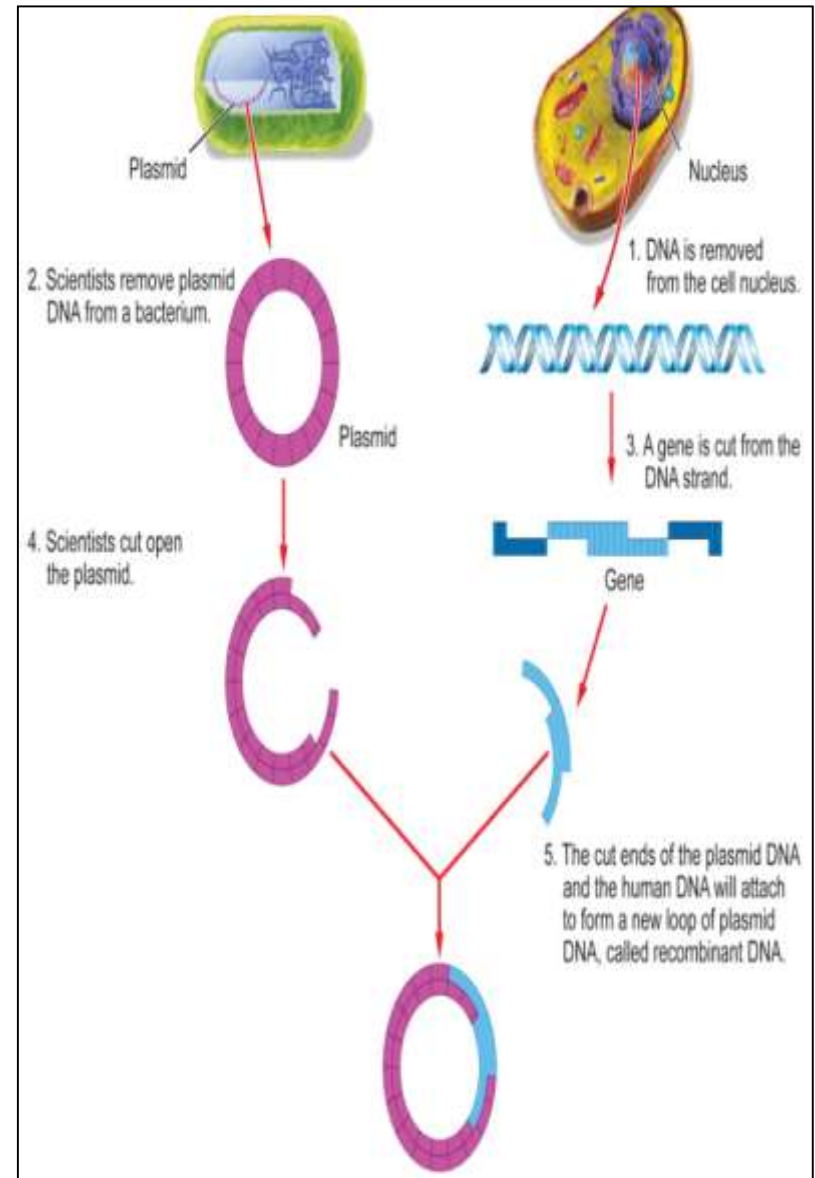
- Manipulation of an organism's genes using biotechnology techniques. Modifications are made using recombinant DNA technologies. Those technologies proceed by combining two or more genes and injecting the construct into the organism.
- Using recombinant DNA technology or other techniques such as CRISPR-Cas9, it is now possible to target and modify precise genetic sequences.

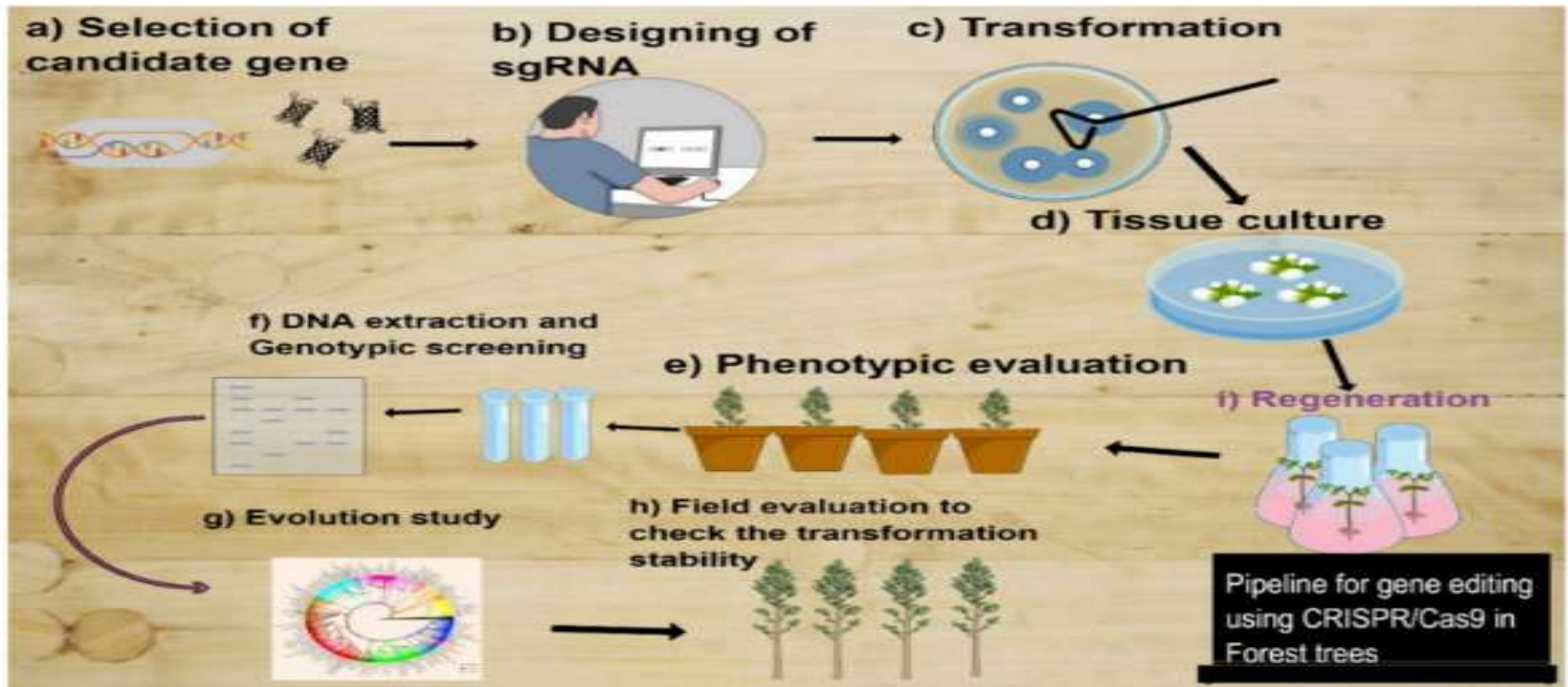
Role in crop improvement:

- It improves crop yields and productivity
- It can introduce disease resistant genes
- It reduces need for pesticides

Procedure:

- Identification of genes that confer desirable traits
- Isolating the identified genes from the source
- Inserting the isolated genes into the target plant's genome
- Introducing modified genes into plant cells
- Selecting plants with desired traits





<https://www.mdpi.com/1422-0067/22/19/10583>

- **Marker-assisted selection (MAS)** is an indirect plant breeding technique that uses genetic markers, like specific DNA sequences, to select plants with desired traits, rather than waiting for the trait to develop or be measured directly.
- This process involves identifying molecular markers closely linked to agriculturally important traits, such as disease resistance or stress tolerance, and then breeding plants that possess these specific markers.
- MAS offers significant advantages, including accelerated breeding programs and the ability to select for traits that are difficult or expensive to measure, are expressed late in plant development, or are controlled by recessive alleles.

Plant genetic resources

Plant genetic resources

- Are the hereditary material in all plant varieties—including crop plants, their wild relatives, landraces, and modern cultivars—that have actual or potential value for food and agriculture.
- This includes all the genetic material that allows plants to adapt to environmental stresses, and it is a fundamental resource for maintaining global food security and improving crops through breeding and biotechnological tools.
- The sum total of hereditary material i.e. all the alleles of various genes, present in a crop species and its wild relatives is referred to as **germplasm**.
- This is also known as genetic resources or gene pool or genetic stock. Important features of plant genetic resources are given below.



Genetic pool represents the entire genetic variability or diversity available in a crop species.

- Germplasm consists of land races, modern cultivars, obsolete cultivars, breeding stocks, wild forms and wild species of cultivated crops.
- Germplasm includes both cultivated and wild species and relatives of crop plants.
- Germplasm is collected from centres of diversity, gene banks, gene sanctuaries, farmer's fields, markers and seed companies.
- Germplasm is the basic material for launching a crop improvement programme.
- Germplasm may be indigenous (collected within country) or exotic (collected from foreign countries)

Germplasm Conservation

Conservation refers to protection of genetic diversity of crop plants from genetic erosion.

In - situ conservation

Conservation of germplasm under natural conditions is referred to as in situ conservation. This is achieved by protecting the area from – human interference, such an area is often called natural park, biosphere reserve or gene sanctuary. NBPGR, New Delhi, established gene sanctuaries in Meghalaya for citrus, north Eastern regions for *Musa*, citrus, *Oryza* and *saccharum*.

Ex - situ conservation

It refers to preservation of germplasm in gene banks. This is the most practical method of germplasm conservation. This method has following advantages.

It is possible to preserve entire genetic diversity of a crop species at one place. Handling of germplasm is also easy. This is a cheap method of germplasm conservation.

Seed banks

Germplasm is stored as seeds of various genotypes. Seed conservation is quite easy, relatively safe and needs minimum space

Seeds

Orthodox seeds

Seeds which can be dried to low moisture content and stored at low temperature without losing their viability for long periods of time is known as orthodox seeds.

Ex. Seeds of corn, wheat, rice, carrot, papaya, pepper, chickpea, cotton, sunflower.

Recalcitrant seeds

Seeds which show very drastic loss in viability with a decrease in moisture content below 12 to 13% are known as recalcitrant seeds.

Ex. citrus, cocoa, coffee, rubber, oil palm, mango, jack fruit etc.

Seed storage

Base collections

Seeds can be conserved under long term (50 to 100 years), at about -20°C with 5% moisture content. They are used only for regeneration.

Active collection

Seeds are stored at 0°C temperature and the seed moisture is between 5 and 8%. The storage is for medium duration, i.e., 10-15 years. These collections are used for evaluation, multiplication, and distribution of the accessions.

Working collections

Seeds are stored for 3-5 years at $5-10^{\circ}\text{C}$ and they usually contain about 10% moisture. Such materials are regularly used in crop improvement programmes.



Plant bank



Cell bank



Seed bank



Pollen bank



DNA bank



Shoot tip bank

Plant Bank: (Field or plant bank)is an orchard or a field in which accessions of fruit trees or vegetatively propagated crops are grown and maintained.

Limitations:

1. Require large areas
2. Expensive to establish and maintain
3. Prone to damage from disease and insect attacks
4. Man – made
5. Natural disasters
6. Human errors in handling

Cell and organ banks: A germplasm collection based on cryopreserved (at – 196°C in liquid nitrogen) embryogenic cell cultures, somatic/ zygotic embryos these can be called cell and organ bank.

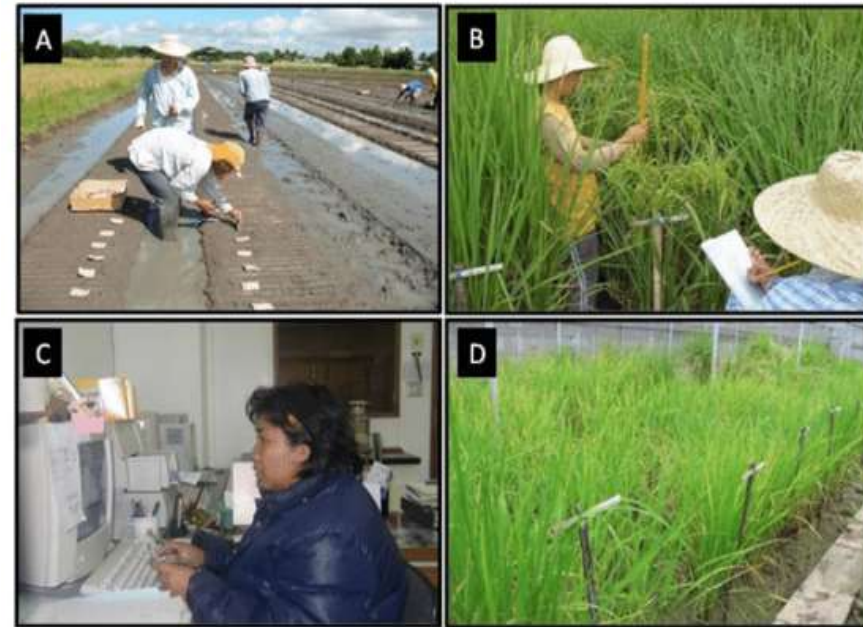
DNA banks: In these banks, DNA segments from the genomes of germplasm accessions are maintained and conserved.

Shoot tip banks: Germplasm is conserved as slow growth cultures of shoot-tips and node segments. Conservation of genetic stocks by meristem cultures has several advantages as given below.

- Each genotype can be conserved indefinitely free from virus or other pathogens.
- It is advantageous for vegetatively propagated crops like potato, sweet potato, cassava etc., because seed production in these crops is poor
- Vegetatively propagated material can be saved from natural disasters or pathogen attack.
- Long regeneration cycle can be envisaged from meristem cultures.
- Regeneration of meristems is extremely easy.
- Plant species having recalcitrant seeds can be easily conserved by meristem cultures.

Germplasm evaluation

- Evaluation refers to screening of germplasm in respect of morphological, genetical, economic, biochemical, physiological, pathological and entomological attributes. Evaluation of germplasm is essential from following angles.
- To identify gene sources for resistance to biotic and abiotic stresses, earliness, dwarfness, productivity and quality characters.
- To classify the germplasm into various groups
- To get a clear pictures about the significance of individual germplasm line.
- IPGRI, Rome has developed model list of descriptors (= characters) for which germplasm accessions of various crops should be evaluated.
- The evaluation of germplasm is done in three different places viz.,
 - (1) in the field
 - (2) in green house
 - (3) in the laboratory



https://www.researchgate.net/figure/Characterization-evaluation-and-documentation-of-rice-germplasm-A-Sowing-of_fig4_263890933

Germplasm cataloguing, Data storage and Retrieval.

Each germplasm accession is given an accession number. This number is pre fixed in India, with either IC (Indigenous collection), EC (exotic collection) or IW (Indigenous wild). Information on the species and variety names, place of origin, adaptation and on its various feature or descriptors is also recorded in the germplasm maintenance records. Catalogues of the germplasm collection for various crops are published by the gene banks. The amount of data recorded during evaluation is huge. Its compilation, storage and retrieval is now done using special computer programmes.

https://agritech.tnau.ac.in/crop_improvement/crop_imprv_plantgeni.html#:~:text=The%20sum%20total%20of%20hereditary,These%20are%20described%20below.

National Bureau of Plant Genetic Resources (NBPGR)

NBPGR establishment in 1976 is the nodal organization in India for planning, conducting, promoting, coordinating and lending all activities concerning plant.

1. Collection
2. Introduction
3. Exchange
4. Evaluation
5. Documentation
6. Safe conservation
7. Sustainable management of germplasm



Functions of NBPGR:

Acquisition and Management of PGR: NBPGR is responsible for the national-level acquisition and management of diverse indigenous and exotic plant genetic resources for agriculture.

Germplasm Conservation: It maintains a National Gene bank for the long-term storage of plant germplasm, including seeds and cryopreserved samples.

Characterization and Evaluation: The Bureau characterizes and evaluates the collected germplasm for various traits to identify valuable material for crop improvement.

Research and Development: NBPGR conducts research on PGR informatics, genomic tools, and molecular profiling to enhance germplasm utilization.

Quarantine and Phytosanitary Services: It provides quarantine checks and issues Phytosanitary Certificates for imported and exported plant materials, including transgenic materials.

Human Resource Development: NBPGR engages in training and education programs to develop a skilled workforce in plant genetic resources management.

Promoting Germplasm Utilization: The Bureau organizes Germplasm Field Days and provides ready material to breeders to develop new crop varieties for farmers.

Information Network Development: NBPGR develops and maintains an information network on plant genetic resources, including mobile applications, to enhance accessibility and utilization.

Vegetable Crop Responsibilities and Germplasm Activities at NBPGR

- The vegetable crop germplasm programme broadly includes the following vegetable crops for evaluation, documentation and maintenance of active collections besides their long term storage:
- The quantum of variability available and of diversity of various vegetable crops shows that India is one of the important centres/regions of variability of vegetable crops. The centre of origin/diversity of various vegetable crops reveals that a number of vegetable crops of economic importance and their wild relatives originated in this region. These genetic resources possess genes for wide adaptability, high yield potential including resistance/tolerance to biotic and abiotic stresses. The Indian sub-continent, thus holds prominence as one of the twelve regions of variability in crop plants in global perspective.

A.	Solanaceae	Brinjal, tomato, chilies
B.	Cucurbitaceous Vegetables	Pumpkin, melons, gourds and cucumber
C.	Leguminous vegetables	Cowpea, pea, lablab bean, winged bean, faba bean, French bean
D.	Bulb crops	Garlic, onion
E.	Root vegetables	Radish, carrot, turnip
F.	Miscellaneous vegetables	Cole crops, Chinese cabbage, spinach beet, spinach, Okra

Gene banks for various crops in India

Institutes	Crops
Central Institute for Cotton Research, Nagpur	Cotton
Central Plantation crops Research Institute, Kasargod	Plantation crop
Central Potato Research Institute, Simla	Potato
Central tobacco research Institute, Rajahmundry	Tobacco
Central tuber crops research Institute, Thiruvananthapuram	Tuber crops other than potato
Central Rice Research Institute, Cuttack	Rice
Directorate of Oilseeds research, Hyderabad	Oilseeds
Directorate of Wheat Research, Karnal	Wheat
Indian Agricultural Research Institute, New Delhi	Maize
Indian Grassland and Fodder Research Institute, Jhansi	Forge and fodder crops
National research centre for sorghum, Hyderabad	Sorghum
International Crops Research Institute for Semi-Arid Tropics	Groundnut, Pearl millet, Sorghum, Pigeon pea and Bengal gram

List of important International Institutes conserving germplasm

Name	Institute	Activity
IRRI	International Rice Research Institute, Los Banos, Philippines	Tropical rice Rice collection: 42,000
CIMMYT	Centre International de-Mejoramientos de maiz Trigo, El Baton, Mexico	Maize and wheat (Triticale, barely, sorghum) Maize collection – 8000
CIAT	Center International de-agricultural Tropical Palmira, Columbia	Cassava and beans, (also maize and rice) in collaboration with CIMMYT and IRRI
IITA	International Institute of Tropical Agriculture, Ibadan, Nigeria.	Grain legumes, roots, and tubers, farming systems.
CIP	Centre International de-papa-Lima. Peru	Potatoes
ICRISAT	International Crops Research Institute, for Semi-Arid Tropics, Hyderabad, India	Sorghum, Groundnut, Cucumber, Bengal gram, Red gram.
WARDA	West African Rice Development Association, Monrovia, Liberia	Regional Cooperative Rice Research in Collaboration with IITA and IRRI
IPGRI	International Plant Genetic Research Institute, Rome Italy	Genetic conservation.
AVRDC	The Asian Vegetable Research and Development Centre, Taiwan	Tomato, Onion, Peppers Chinese cabbage.